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NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

MODELING AND SIMULATION SUPPORT FOR THE OPERATIONAL TEST AND EVALUATION OF A TACTICAL AIRBORNE RECONNAISSANCE SYSTEM

by

Kevin J. Schmidt

December 1999

Thesis Advisor:	Donald P. Gaver
Co-Thesis Advisor:	Patricia A. Jacobs
Second Reader:	Arnold H. Buss

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Today's decreasing defense budget has forced the military to reduce its spending on operational testing of new equipment, among many other areas. Reduced testing has forced evaluators to focus their attention on possible sensitive issues prior to and during testing of new equipment. The Simulation, Test, and Evaluation Process implemented in 1995 to help reduce testing costs has been an integral part of the test and evaluation process.

This thesis develops stochastic simulations to suggest the sensitive aspects of operating and maintaining a system of mobile reconnaissance platforms, specifically a helicopter force, (more specifically the RAH-66 Comanche) prior to and during actual testing. The simulation can also be implemented to compare the effectiveness of different mobile reconnaissance platforms to augment the conduct of side-by-side field testing of actual platforms.

This simple, stochastic, event-driven simulation may be used to conduct sensitivity analysis on system design and operational issues, including attrition, for mobile reconnaissance platforms in order to focus the attention of the testers and evaluators on influential parameters during testing. It may also be used to inform force design decision-makers.

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MODELING AND SIMULATION SUPPORT FOR THE OPERATIONAL TEST AND EVALUATION OF A TACTICAL AIRBORNE RECONNAISSANCE SYSTEM

Kevin James Schmidt
Lieutenant, United States Navy
B.S., United States Naval Academy, 1993

Submitted in partial fulfillment of the
requirements for the degree of

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December 1999

Author: [redacted]
Kevin J. Schmidt

Approved by: [redacted]
Donald P. Gaver, Thesis Advisor

[redacted]
Patricia A. Jacobs, Co-Thesis Advisor

[redacted]
Arnold H. Buss, Second Reader

[redacted]
Richard E. Rosenthal, Chairman
Department of Operations Research

ABSTRACT

Today's decreasing defense budget has forced the military to reduce its spending on operational testing of new equipment, among many other areas. Reduced testing has forced evaluators to focus their attention on possible sensitive issues prior to and during testing of new equipment. The Simulation, Test, and Evaluation Process implemented in 1995 to help reduce testing costs has been an integral part of the test and evaluation process.

This thesis develops stochastic simulations to suggest the sensitive aspects of operating and maintaining a system of mobile reconnaissance platforms, specifically a helicopter force, (more specifically the RAH-66 Comanche) prior to and during actual testing. The simulation can also be implemented to compare the effectiveness of different mobile reconnaissance platforms to augment the conduct of side-by-side field testing of actual platforms.

This simple, stochastic, event-driven simulation may be used to conduct sensitivity analysis on system design and operational issues, including attrition, for mobile reconnaissance platforms in order to focus the attention of the testers and evaluators on influential parameters during testing. It may also be used to inform force design decision-makers.

THESIS DISCLAIMER

The reader is cautioned that computer programs developed in this research may not have been exercised for all cases of interest. While every effort has been made, within the available time, to ensure that the programs are free of computational and logic errors, they cannot be considered validated. Any application of these programs without additional verification and validation is at the risk of the user.

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EXECUTIVE SUMMARY

The Operational Test and Evaluation (OT&E) of a new weapon system is that part of the acquisition process that determines whether the weapon system is operationally effective and operationally suitable in the combat environment for which it was designed when operated by typical users. Because of the increasing costs of conducting tests, testers and evaluators must be focused on the important and highly sensitive operational issues needed to ensure successful fielding of a new weapon system.

Modeling and Simulation (M&S) is a useful way of beginning to understand what a particular system will be able to accomplish, and can be used as an aid in the determination of sensitive operational issues. This thesis develops a simple, stochastic, event-driven simulation to identify sensitive aspects (parameters) of operating and maintaining a mobile reconnaissance platform, specifically a helicopter. The simulation has been built to provide support for the Operational Test and Evaluation of the RAH-66 Comanche. Specifically, the simulation is used to identify the influential parameters involved in operating and maintaining the Comanche as a reconnaissance system by conducting sensitivity analysis of the input parameters to determine the effects of each on selected Measures of Effectiveness (MOE).

One MOE used throughout this thesis is the mean percentage of time that a team of helicopters is on station providing reconnaissance coverage of a Named Area of Interest (NAI) on each day of the campaign. The MOE is the total amount of time per day that at least one helicopter is providing coverage of the NAI divided by the total amount of time in a day, averaged over numerous replications. Another MOE used is the

mean number of helicopters surviving at the end of each day during the campaign. This measure of effectiveness shows the rate of decline in the number of helicopters over time resulting from attrition by enemy forces and helicopter crashes. Additional MOEs can be computed as determined by the needs of the user.

Several parameters were varied in the conduct of sensitivity analysis for two models used to generate times between mission-affecting failures. One model, a Weibull distribution, demonstrated that not only is the mean time between mission-affecting failures an influential parameter, but that the shape of the distribution is highly influential as well. The shape of the Weibull distribution represents the type of failures that are predominately experienced. For a shape parameter less than one many short failure times are generated (infant failure), while a shape parameter greater than one (wear-out) will produce many failure times clustered around the mean of the distribution.

The other model used to generate times between mission-affecting failures is a time dependent non-homogeneous Poisson process. This process represents aging of the helicopters. As more flight time is accumulated, shorter times between mission-affecting failures are generated and thus more mission-affecting failures occur.

The vulnerability of reconnaissance platforms proved to have the largest effect on the MOEs in both models. In most instances the vulnerability parameters dominate effects of the other parameters. This suggests that the vulnerability of the helicopters needs to be addressed and monitored during operational testing.

By obtaining information about the sensitive aspects of weapon system operations prior to actual testing, the testers and evaluators can design tests specifically to look at the

above mentioned issues. This thesis demonstrates the use of a simple stochastic simulation to identify influential parameters involved in operating and maintaining a mobile reconnaissance platform. Its use can provide valuable insights into complex operational issues.

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Finally, I would like to thank my loving wife Libby, whose love and patience have shown no bounds throughout this endeavor.

I. INTRODUCTION

A. GENERAL

The Operational Test and Evaluation (OT&E) of a new weapon system is that part of the acquisition process that determines whether the weapon system is operationally effective and operationally suitable in the combat environment for which it was designed, when operated by typical users. Because of the increasing costs of conducting tests, testers and evaluators must be focused on the important and highly sensitive operational issues needed to ensure successful fielding of a new weapon system. Sensitive operational issues are those aspects of the weapon system that, when changed slightly, cause a significant variation in the operational suitability and/or effectiveness of the weapon system. With their attention focused on the sensitive operational issues, testers and evaluators can plan tests more efficiently to examine a system's operational performance with regard to several issues at once rather than conducting several tests to obtain all the required data for the analysis of the new weapon system. Modeling and Simulation can increase the efficiency and timeliness of the acquisition process.

A primary OT&E issue is to decide whether a particular new or upgraded weapon system will be a valuable addition to the force, where value must include its general operational capability (including range, reliability, availability and maintainability) plus its life-cycle cost, compared with alternatives. Modeling and Simulation (M&S) is a useful way of beginning to anticipate what a particular system will be able to accomplish and cost, under realistic conditions. More importantly, M&S will help to focus attention

on possibly sensitive aspects of system design and operation prior to actual tests (Stoneman, 1998).

This thesis develops a stochastic simulation to identify sensitive aspects (parameters) of operating and maintaining a mobile reconnaissance platform, specifically a helicopter, prior to and during actual field-testing. The simulation has been built to provide support for the Operational Test and Evaluation of the RAH-66 Comanche. With some parameter adjustments, the same simulation can be used to evaluate many other reconnaissance platforms.

B. PROBLEM

During OT&E, the Department of Defense (DoD) user must oversee the operational test of certain weapon systems to ensure that they meet operational requirements, defined during and before the developmental phase of the acquisition process. Many of these requirements are specifically designated in the Operational Requirements Document (ORD). It is the testers' and evaluators' responsibility to ensure that the platform is able to meet or exceed the requirements specified in the ORD.

However, when initially entering the testing phase, the testers and evaluators may not know which aspects of the weapon system are of great importance to successful operation in the field. Prior to conducting actual tests, testers and evaluators, and the program manager and eventual user force, will have many questions about the operation and/or design of the weapon system, its operational sensitivities and their effect on mission accomplishment. Some of these questions can be answered using a stochastic simulation designed to conduct sensitivity analysis. The answers to these questions will

focus the attention of the testers and evaluators on issues of system design and operation prior to actual tests. By knowing what to look for during testing, the testers and evaluators will be able to focus on the significant operational issues and ensure that the weapon system meets its specified requirements during operational testing. Properly employed, system modeling and simulation will assist in cost-effective fielding of new and upgraded weapons.

C. PURPOSE

The purpose of this thesis is to aid in the Operational Test and Evaluation of the RAH-66 Comanche helicopter using a simple, event-step, stochastic simulation. The simulation, developed for this thesis, will be used to identify influential parameters involved in operating and maintaining the RAH-66 Comanche as a reconnaissance platform system prior to, and during, operational testing (OT). The question being answered is:

> Which aspects of operation and maintenance of the Comanche helicopter greatly affect its ability to perform the reconnaissance mission?

The model developed for this purpose can also be used for many other similar purposes, and analogous situations and systems: for T&E guidance and force design for force elements that are failure-susceptible, vulnerable, and of limited endurance.

D. SCOPE

The scope of this thesis is to determine how variations of the input parameters affect a measure of effectiveness. One measure of effectiveness (MOE) used throughout

this thesis is the mean percentage of time that a helicopter or team of helicopters is on station providing reconnaissance coverage of the search area or Named Area of Interest (NAI) on each day of the campaign. The MOE is the total amount of time per day that at least one helicopter or team of helicopters is providing coverage of the NAI divided by the total amount of time in a day, averaged over numerous runs. Another MOE used is the mean number of helicopters surviving at the end of each day during the campaign. This measure of effectiveness shows rate of decline in the number of helicopters over time resulting from attrition by enemy forces and helicopter crashes. The mean number is also augmented by selected (25%, 50% and 75%) percentiles of those surviving to portray risk.

To facilitate understanding, several input parameters are varied to determine the extent of each varied parameter's effects on the measures of effectiveness. Plausible alternatives for generating the random times between mission-affecting failures are modeled for their effect on the results, as are alternative maintenance strategies and capabilities. It is shown that changes in the distribution of time to failure can importantly affect overall system performance; these sensitivities can be efficiently discovered by simulation (Stoneman, 1998).

By using a simple stochastic simulation to discover the sensitive issues of the RAH-66 Comanche helicopter system, testers and evaluators can effectively plan tests and make better use of output data from such tests. The data collected during each test run of the helicopter system can be used to verify the predictions of the simulation and modify the simulation model, if necessary, for future simulations prior to further

operational testing. This is an example of the "model, test, modify, and (re)model, test..." paradigm of modern Test and Evaluation.

II. BACKGROUND

Operational Test and Evaluation is traditionally defined as the field test, under realistic combat conditions, of any system of weapons, equipment, or munitions for the purpose of determining the Effectiveness and Suitability of the weapons, equipment, or munitions for use in combat by typical military users, and the evaluation of the results of such a test (DoDD 5141.2, 1989). This is as defined in DoDD 5141.2, "Director of Operational Test and Evaluation," which establishes and defines the responsibilities for the Director, Operational Test and Evaluation (DOT&E). Operational Test and Evaluation is performed to ensure that before accepting delivery and offering complete payment for the systems, DoD has tested them to ensure that they are operationally effective and operationally suitable in the intended combat environment when operated by typical users. From this precept has sprung an extensive policy directing how and when such testing must be done, and by whom (Carter, 1998).

Operational Effectiveness represents the overall degree of mission accomplishment of a system when used by representative personnel in the environment planned or expected (e.g., natural, electronic, threat) for operational employment considering organization, doctrine, tactics, survivability, vulnerability, and threat (http://web.nps.navy.mil/~orfacpag/resumePages/gaver/planning.htm). Operational Suitability suggests the degree to which a system can be placed satisfactorily in field use with consideration given to availability, compatibility, transportability, interoperability, reliability, wartime usage rates, maintainability, safety, human factors, manpower

supportability, logistics supportability, natural environmental effects and impacts, documentation, and training requirements

(http://web.nps.navy.mil/~orfacpag/resumePages/gaver/planning.htm).

Even though much of the testing is directed by policy, the detailed focus of the tests is not always straightforward. Since 1995, the Simulation, Test and Evaluation Process (STEP) has been a required, integral part of the test and evaluation process. The STEP process, a repetitive cycle of "model, test, model," allows the testers and evaluators to gain insight into the system prior to conducting any actual field tests. Modeling and Simulation (M&S) is used to gain insights into operational consequences (O'Bryan, 1998). A simulation is formulated to represent the system and then run numerous times to gain an understanding of the mean and variability of measures of operability for the actual system and its characteristics. The simulation focuses the attention of the testers and evaluators on sensitive issues that should be addressed or monitored during actual testing. As Mr. Philip E. Coyle, current Director, Operational Test and Evaluation in OSD, said in a presentation, "Modeling and Simulation and testing are intertwined; when they are not, neither is effective" (Coyle, 13 May 1999).

The following quote shows that the entire acquisition community has been directed to implement and use modeling and simulation throughout the entire acquisition process. "Test and evaluation programs shall be structured to integrate all developmental test and evaluation (DT&E), operational test and evaluation (OT&E), live-fire test and evaluation (LFT&E), and modeling and simulation (M&S) activities conducted by different agencies as an efficient continuum. All such activities shall be part of a strategy

to provide information regarding risk and risk mitigation, to provide actual data to accredit models and simulations, to permit an assessment of technical performance specifications and to determine whether systems are operationally effective, suitable and survivable for intended use" (DOD 5000.2-R, Section 3.4, 1999).

Many models and simulations are available for use. Some are high-resolution models, with a narrow focus, which are often costly to operate and reprogram to represent operational situations. Examples of high-resolution models are FAST3D and PARACOMT. Both model the effects of chemical and biological warfare by providing high-fidelity assessments of chemical agent cloud movements and target area coverage along with personnel casualty estimates respectively (https://www.msrr.dmso.mil/KeywordMain.htm). Models of this nature provide more detail than is necessary to gain an understanding of the underlying processes that are important to the operational effectiveness of a system. More often than not, these types of models require a vast amount of computing power as well as a great deal of time to provide useful output.

Other models are very low resolution; they do not provide a detailed enough view of a specific "piece of the action," but provide a big picture overview of everything. Examples of low-resolution models are CEM and IDAGAM. These are both deterministic theater-level models of ground and air-combat whose basic units are either a division or brigade (Hartman, Parry, Caldwell, 1992). These types of models may not have sufficient detail to answer the questions posed by weapon system developers, testers and evaluators.

Many times the model or simulation needed to study the contribution of a specific system does not exist. In this case, new models or simulations can be constructed quickly and inexpensively, and run on a personal computer to provide an analysis tool that fits the tailored needs of the current weapon system being tested. Models of this type are very inexpensive to operate, can be distributed to many users to allow increased analysis, and are tailored to answer the exact questions that have been posed by the decision-makers. One such question addressed by the current model is: "How does attrition by enemy forces affect mission accomplishment?" Models, such as MASS and UAVSim, have been developed to study area coverage and maintenance policies for various platforms (Stoneman, 1998; Heath, 1999). Neither of the previous models has addressed the issue of attrition. Attrition reduces the number of available platforms and thereby affects mission accomplishment. The current model addresses this issue and its effects.

Even though a model is "unaccredited," i.e., not officially approved for use, it can still produce valuable insights into testing (Coyle, 1998). It is this type of model that is created and exercised (used to provide test design insights) in this thesis.

III. MODEL DEVELOPMENT

A. OVERVIEW

The model developed is realized as a stochastic, event-driven simulation, which simulates the operation of a tactical reconnaissance platform, e.g., a helicopter (but not exclusively). The model is programmed in Java using the simulation package Simkit that was developed by Arnold Buss and Kirk Stork (Stork, 1997). The model consists of four Java classes or entities:

1) Helicopter

2) Helicopter Manager

3) Threat Area Manager

4) Maintenance Manager

The objective of the model is to represent an operation that sends reconnaissance assets, i.e., helicopters traveling in pairs, from a home base to a search area via waypoints to conduct a search of a Named Area of Interest (NAI). While in transit to and from the search area the helicopters are subject to mission-affecting failures, and are also vulnerable (can be shot down by enemy forces) to differing degrees in different areas, as shown in Figure 1. Retaliation or suppression of Red enemy defensive fire is not modeled here, but its effect may be represented by reducing the vulnerability rate. If a helicopter experiences a mission-affecting failure, it immediately returns to its home base for repairs. If a helicopter is shot down, it is assumed lost and removed from the simulation. Further losses from pilot rescue are also not modeled here. Once a helicopter

completes a mission or returns to its home base due to a mission affecting-failure, it is sent to the maintenance facility for repairs, rearming and refueling. The number of mission-affecting failures that the helicopter experienced during its previous mission as well as additional turn-around time (rearming and refueling) determines the time spent in the maintenance facility for repairs. The model also monitors total flight time for each helicopter and after a specified number of flight hours (e.g., 300 hours) each helicopter is sent to the maintenance facility for scheduled maintenance. The scheduled maintenance period is an extended period of time (e.g., 7 days) during which the helicopter is overhauled. Such overhaul reduces system failure rate to its initial level. A chart depicting the flow of model operation is shown in Figure 2.

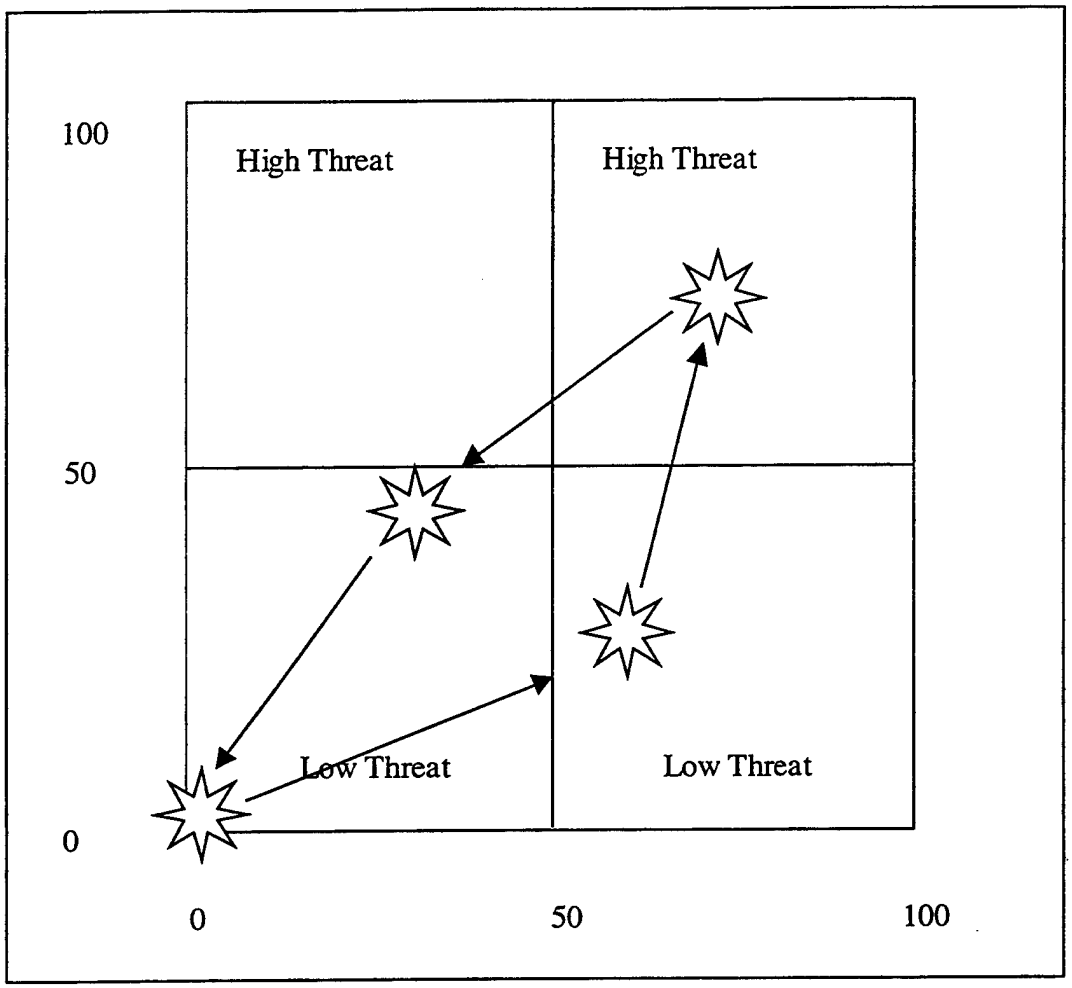

Figure 1. Chart of the Operation Area. The home base is located at the origin with the search area in the high threat region. The ingress and egress waypoints are located in the low threat regions.

One prominent measure of effectiveness (MOE) used to compare different platforms, different initial conditions, and different operational policies is the *mean percentage of time that a group of such reconnaissance platforms, operating cooperatively, can maintain coverage over the search area.* Another MOE used is the *mean number of helicopters surviving at the end of each day.* Other measures can also be studied using the model's software to extract the necessary data from the simulation.

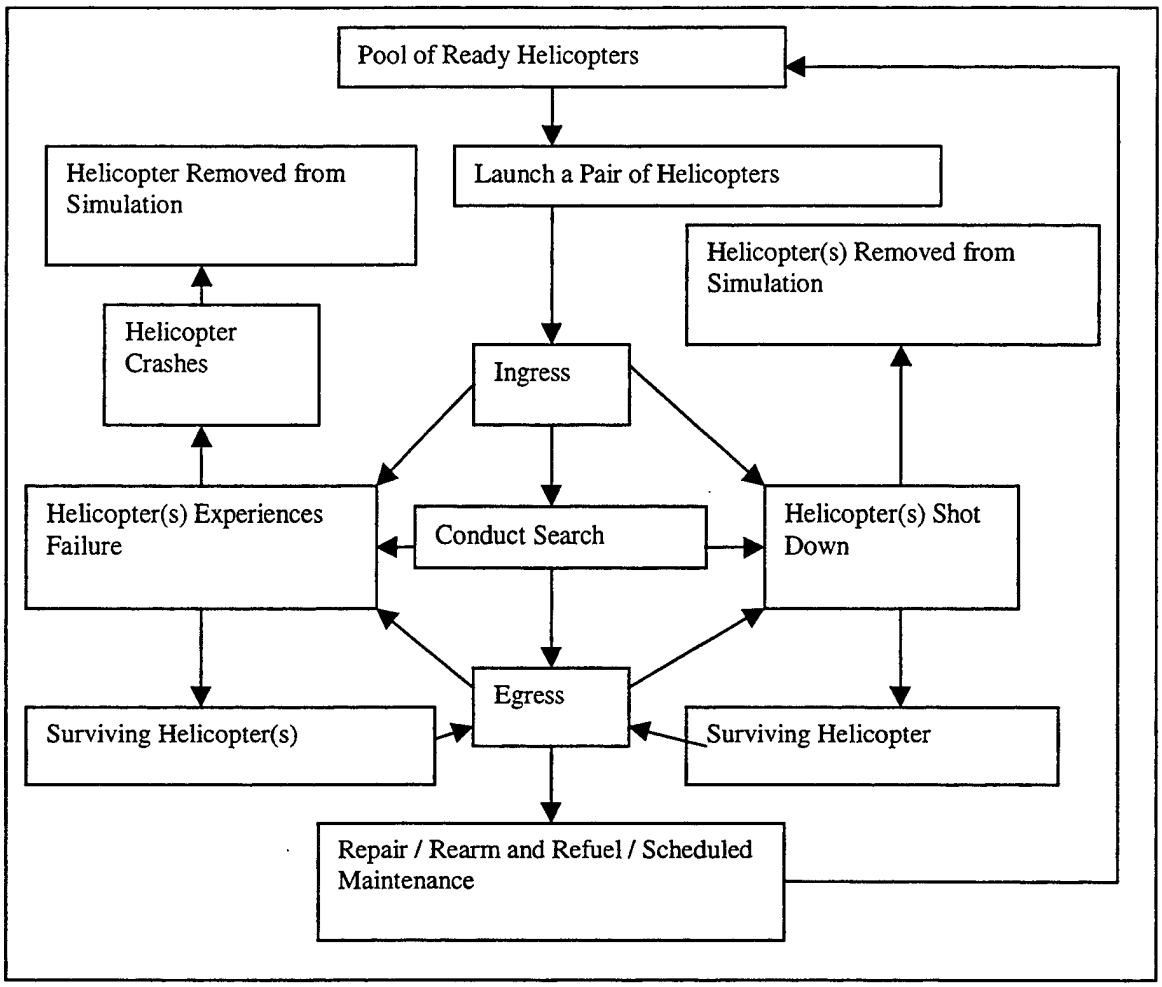

Figure 2. Chart of the Model Flow. This chart depicts the flow of the model as it directs helicopters to accomplish the mission of maintaining coverage over the search area.

B. CLASS (ENTITY) DESCRIPTIONS

1. Helicopter

Each reconnaissance asset (helicopter) can ingress to the search area, search the search area, egress from the search area, fail, be shot down, be refueled and rearmed, be repaired, overhauled, and often it must, by doctrine, be assigned a partner or wingman.

When a helicopter experiences a mission-affecting failure, it either forces the helicopter to return to its home base or destroys the helicopter at the time of failure

(crashes). The times between mission-affecting failures (MAF) can be modeled using various potentially appropriate stochastic processes. One of the processes examined in this thesis assumes the times between MAF are independently and identically distributed having a Weibull distribution (specified by shape and scale parameters and hence a specified mean time to failure). Another process examined assumes the times between MAF are the times between arrivals of a non-stationary Poisson process that emulates the effects of aging which can be reversed by periodic overhauls. These distributions were created in separate Java classes for use with Simkit. When a helicopter is shot down, it is simply removed from the simulation. Helicopter replacements and reinforcements are not modeled at present. While performing a mission, each helicopter is assigned a partner or wingman. If the helicopter's partner experiences a mission-affecting failure or is shot down, the surviving helicopter is notified of this event and in both cases is directed to return to its home base.

Each helicopter monitors and updates its state variables as it progresses through the simulation. The state variables monitored are the number of mission-affecting failures per mission, state of helicopter flight (ingress, search, or egress), total flight time or flight hours, whether the helicopter is dead or alive, and the state of the helicopter's partner or wingman while in flight. At the start of each simulation, each helicopter's initial flight hours are set such that the arrival of helicopters to the maintenance facility for periodic overhauls is staggered. This practice of staggering periodic overhauls is normal for actual helicopters or any other equipment that periodically requires time intensive maintenance.

2. Helicopter Manager

The helicopter manager controls the movement of all the helicopters that are created for the simulation. If any event or movement occurs to a helicopter, the helicopter manager controls it. The helicopter manager directs the helicopters to and from their search area via the helicopter's ingress and egress waypoints. It also directs the helicopters to return to their home base via the most direct route in the event of a mission-affecting failure. The helicopter might also divert if the enemy were known to be dense along the direct route; this is not represented here. If a helicopter is shot down, the helicopter manager directs the surviving helicopter to return to its home base via the most direct or minimum-risk route. Barring any failures or attrition, the helicopter manager is designed to control the helicopters to maintain continuous coverage of the search area.

The helicopter manager also directs the helicopters to the maintenance manager for failure repairs or periodic maintenance. Before sending a helicopter on a mission, the helicopter manager compares the helicopter's flight hours to its periodic scheduled maintenance time. If the helicopter has sufficient flight hours remaining to complete another mission, it is sent on the mission. Otherwise the helicopter is sent to the maintenance manager for scheduled maintenance. Upon completion of the repairs or the scheduled maintenance, the helicopter is returned to the helicopter manager where it awaits assignment of its next mission.

3. Threat Area Manager

The threat area manager is a simulation program entity that keeps track of where the helicopter is in relation to pre-assigned threat areas and assigns times until the

individual helicopters get shot down. A threat area manager is assigned to each helicopter.

The time until being shot down in a threat area is modeled with an exponential distribution specified by the assumed mean time until an individual helicopter is shot down in that area. As the helicopter enters and leaves the pre-assigned threat areas, its threat area manager will change the time until the helicopter is shot down based on the threat area that the helicopter is entering. If a helicopter is shot down, both the helicopter and its threat area manager are removed from the simulation. Occasional recovery of crashed helicopters (certainly their surviving crew) is plausible, but not covered by the present models.

4. Maintenance Manager

The maintenance manager (a simulation device, but one that reflects and approximates the actions of an actual scheduler) is responsible for generating the repair, turnaround, and scheduled maintenance times for the helicopters. The turnaround time is the time to refuel and rearm the helicopter to prepare it for its next flight. The maintenance system is a specialized multi-type customer and server queuing system; it is a complicated "repairman problem," (Feller, 1967). Separate servers are used for the repair (includes turnaround) and scheduled maintenance systems that the maintenance manager controls.

As each helicopter enters the repair system, it is assigned a repair time for each of its failures, and a turnaround time. In the present model, both of these times are exponentially distributed, but other distributions may be easily substituted. The repair

system can be operated on a first-come, first-served basis or, more realistically, it can be set up as a priority queuing system that might start repair on the helicopter in the queue with the shortest total repair and turnaround time. This assumes that the repair times for each of the helicopters in the queue are known. This is a reasonable assumption due to the high technological systems of modern day equipment with sophisticated and reliable fault detection. The repair system can also be set up with multiple repair facilities.

The maintenance manager also controls the helicopters that require scheduled maintenance. Each helicopter that enters the maintenance system for scheduled maintenance is assigned a random maintenance time, taken to be uniformly distributed over an interval restricted around seven days. The maintenance times are generally many times greater than the repair times since the scheduled maintenance simulates the helicopters being periodically overhauled. Once a helicopter completes its scheduled maintenance, it is returned to the helicopter manager. The model can be set up so that, upon completing scheduled maintenance, the helicopter is returned to the helicopter manager in perfect condition or near-perfect condition. Either way, the helicopter is always returned to service in much better condition (lower failure rate) than when it entered the maintenance facility for scheduled maintenance.

C. OUTPUT

The model writes its output to a text file. The file lists, for each run, the fraction of time per day that at least one helicopter-team is searching over the named area of interest (NAI) and the number of helicopters surviving at the end of each day. The times are then combined to provide the mean percentage of time per day that helicopter-teams

are providing coverage over the NAI. *Note: The 25th, 50th, and 75th percentiles of the distribution of percent coverage of the NAI are also computed; the results appear in Appendix B, Appendix C, and Appendix D. Helicopter Survivability is also tabulated similarly.* The number of helicopters surviving each day is also combined to provide a mean number of helicopters alive at the end of each day. These are the two primary Measures of Effectiveness (MOE) used to make comparisons among the different simulations. By comparing the data for different platforms as well as different initial conditions, T&E decision makers are able to determine which input parameters are highly influential and need to be monitored or tested during field operational testing.

D. SETUP AND ASSUMPTIONS

The purpose of the simulation model is to usefully represent the behavior of actual helicopters in the field. The first item of concern is the helicopter units used for each replication. The doctrine being written for the RAH-66 Comanche helicopter currently calls for three Air Calvary Troops consisting of eight Comanche helicopters each to make up one Division Calvary Squadron. There is one Calvary Squadron per Army Division for a total of 24 RAH-66 Comanche helicopters. Actual practice dictates that the total flight hours of each helicopter be staggered such that the helicopters each enter scheduled maintenance sequentially staggered and not all at once. With this in mind at the start of each simulation replication, the total flight hours for each helicopter are uniformly staggered between zero and the time between scheduled maintenance actions. This means that for 24 helicopters, operating with a scheduled time between maintenance of 300 hours, each helicopter's flight hours are staggered by 12.5 (300/24) hours.

The operation of the maintenance and repair facilities is also set up to reflect actual practices in the field. There is a separate scheduled maintenance facility and a repair facility that operate independently of each other. In the model, the scheduled maintenance facility, which corresponds to depot level maintenance, is strictly responsible for the conduct of overhauls, while the repair facility is strictly responsible for the repair of mission-affecting failures as well as turnaround of the helicopters. In real life this may not always be the case as the company's repair department can become overwhelmed, at which point the commander can request additional help from depot level maintenance. The model is also set up to reflect imperfect repair of failures. When a MAF occurs, a new MAF time is generated from the applicable distribution. Once the helicopter reaches its home base, it is immediately sent to the repair facility to be repaired. The helicopter retains the scheduled time of the next MAF for use on its next mission. Once repairs are complete and the helicopter begins a new mission, a MAF time is not generated. The remaining time until the next MAF that was scheduled is now used as the time until the next MAF for the helicopter. If the helicopter is returning from scheduled maintenance, the previous mission-affecting failure time is disregarded and a new failure time is generated.

The current simulation only generates mission-affecting failures. Non-mission affecting failures are not represented in the present model. The non-mission-affecting failures can be thought of as failures of components or systems with built in redundancy. They could degrade, but possibly not completely eliminate the operational performance of the helicopter since the helicopter would not be forced to abandon its mission. The non-mission-affecting failures would increase the amount of time spent in the repair system,

as these failures should be repaired prior to sending a helicopter on its next mission. The impact of non-mission-affecting failures can be included later, but the mission-degrading tendency should be followed during OT&E.

The mission of the helicopters is to maintain continuous coverage on a Named Area of Interest for a 2 or 3 week period. This is an exceptionally long period of time to attempt to maintain continuous coverage. During that time, the NAI may have lost its significance or even been destroyed, at which point, coverage would no longer be necessary. The model makes the assumption that the NAI is significant and coverage needs to be maintained for the entire time period. If this is not the case, as is typical, the reader can assume that other Named Areas of Interest have been selected that are located at roughly the same distance and flying time from the helicopter's home base, and that coverage of these is the scouting mission.

The base unit of time in the simulation model is the hour. All time measurements are reflected in hours and each day is 24 hours long. The MOEs used, the mean percent coverage of the NAI per day and the mean number of helicopters surviving at the end of each day, have each incorporated the events of the previous 24 hour time-period for which it is reporting data.

IV. MODELS IN WHICH THE TIMES BETWEEN MISSION-AFFECTING FAILURES ARE INDEPENDENT HAVING A WEIBULL DISTRIBUTION

The Weibull distribution may be used to model the random times between mission effecting failures. This distribution is very versatile and useful for a wide range of applications related to system or component failures. The Weibull distribution is specified with shape and scale parameters (always greater than zero) that implicitly define the mean and variance for the distribution. It is generally used to represent time-stable random times between failures of a component or system; such a model does not represent wear-out or aging (this is done next). The Weibull distribution is used for that purpose in this thesis. All values generated by the distribution are greater than zero and the simplest, and most recognized Weibull distribution is that with a shape parameter of one. The mean for this distribution is equal to the scale parameter and the distribution is more commonly referred to as the exponential distribution. The versatility of a Weibull distribution is realized by changing the shape parameter in order to obtain different behaviors by the random numbers generated from the distribution. With a shape parameter less than one, the Weibull distribution generates many small, but positive, values, balanced by some that are quite long to obtain a required mean. This type of behavior is referred to as *infant failure* since many short failure times are generated.

Setting the shape parameter greater than one will result in a distribution centered about the value of the scale parameter. This type of behavior is referred to as *wear-out*

since few short failure times are generated with many longer failure times generated near the mean of the distribution.

The MOEs displayed in this chapter are the mean percent coverage per day of the NAI and the mean number of helicopter surviving at the end of each day. The 25^{th}, 50^{th}, and 75^{th} percentiles for each of the MOEs appear in Appendix B. Appendix B also displays for a campaign the mean number of MAF, mean number of fatal failures, and mean number of helicopters shot down. The mean repair and turnaround time, mean number of missions started, probability of returning to base safely, mean time spent in the high threat regions, mean survival time of individual helicopters, and the mean number of helicopters in the repair system for each campaign are also displayed in Appendix B.

A. SENSITIVITY ANALYSIS OF WEIBULL SHAPES

The shape of the Weibull distribution, used to model the mean time between mission-affecting failures, determines the type of behavior that the failures will exhibit. Using the same mean time between mission-affecting failures (MTBMAF), this section examines the effects of different shapes of the Weibull distribution on MOEs. The cases chosen for comparison are shown below in Table 1.

	Shape	Scale	Mean
Case I	0.5	4.25	8.5 Hours
Case II	1.0	8.5	8.5 Hours
Case III	2.0	9.591223	8.5 Hours

Table 1. Description of Weibull Cases.

The other inputs, which remain constant, are as follows:

Numerical Illustration

⇒	24	Number of Helicopters
⇒	160	Speed of Helicopters (knots)
⇒	300	Time between Scheduled Maintenance Actions (flight hours)
⇒	40	High-Threat Vulnerability (Mean Time until a Helicopter is Shot Down in Region) (hours)
⇒	80	Low-Threat Vulnerability (Mean Time until a Helicopter is Shot Down in Region) (hours)
⇒	1	Repair Facilities
⇒	1	Scheduled Maintenance Facilities
⇒	1	Mean Time to Repair a Failure (hours-Exponentially Distributed)
⇒	0.25	Mean Time of Helicopter Turnaround (hours-Exponentially Distributed)
⇒	144-192	Minimum/Maximum Time to Complete Scheduled Maintenance (hours-Uniformly Distributed)
⇒	0.1	Probability of a failure being fatal (Crash)

One hundred runs of the simulation were conducted for a two-week campaign to observe the effects of the varying Weibull distribution shapes on the mean percent coverage per day of the NAI as well as the mean number of helicopters surviving at the end of each day. Figure 3, Figure 4, and Figure 5 graphically show how the mean percent coverage varied per day as well as the mean number of helicopters remaining at the end of each day. The vertical bars display the mean percent coverage per day of the NAI with the values located on the left vertical axis. The line graph displays the mean number of helicopters that are still alive at the end of each day with the values located on the right vertical axis. The error bars are set at plus and minus one standard error to indicate the variability of the simulation results.

The results show that as the shape of the Weibull distribution increases (the behavior shifts from infant failure to wear-out) the mean number of failures decreases. A significant difference in the mean percent coverage of the NAI and the mean number of

helicopters surviving is shown for the first two days of the campaign. This large difference in mean percent coverage of the NAI is a direct result of the shape of the Weibull distribution. For the case using a shape parameter of 0.5, the helicopters experience infant failures that prevent many of the helicopters from completing their assigned mission. This then results in less coverage of the NAI. The higher number of infant failures also accounts for the lower mean number of helicopters surviving. With more mission-affecting failures occurring initially, more of these failures will result in the helicopters crashing and thus decreasing the mean number of helicopters surviving. As the campaign continues, the wear-out mission-affecting failures for Case III begin to take their toll on the helicopters so that by the end of the campaign there is very little difference in the mean percent of coverage or the mean number of helicopters surviving compared to the other cases. This emphasizes the fact that the type of failures experienced (in part, the shape of the time-to-failure distribution) is just as important as the mean time between mission-affecting failures. Note that all numbers given are notional and illustrative only, but the results point to effects to become aware of during OT&E.

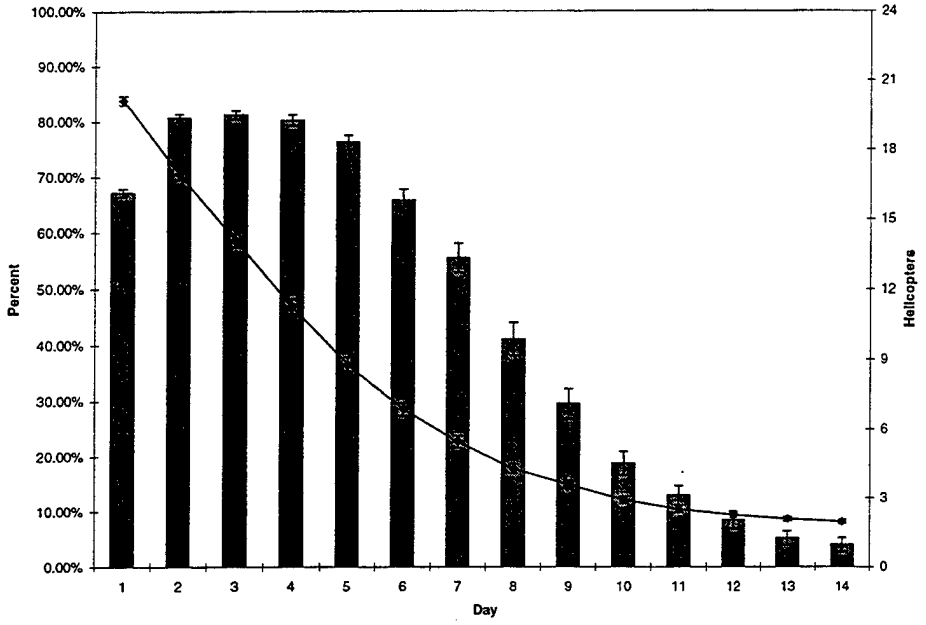

Figure 3. MOEs for a Weibull Distribution with a Shape of 0.5. Case I from Table 1 that shows the effects of a Weibull distribution with a shape parameter of 0.5 and a MTBMAF of 8.5 hours on the mean percent coverage and the mean number of surviving helicopters.

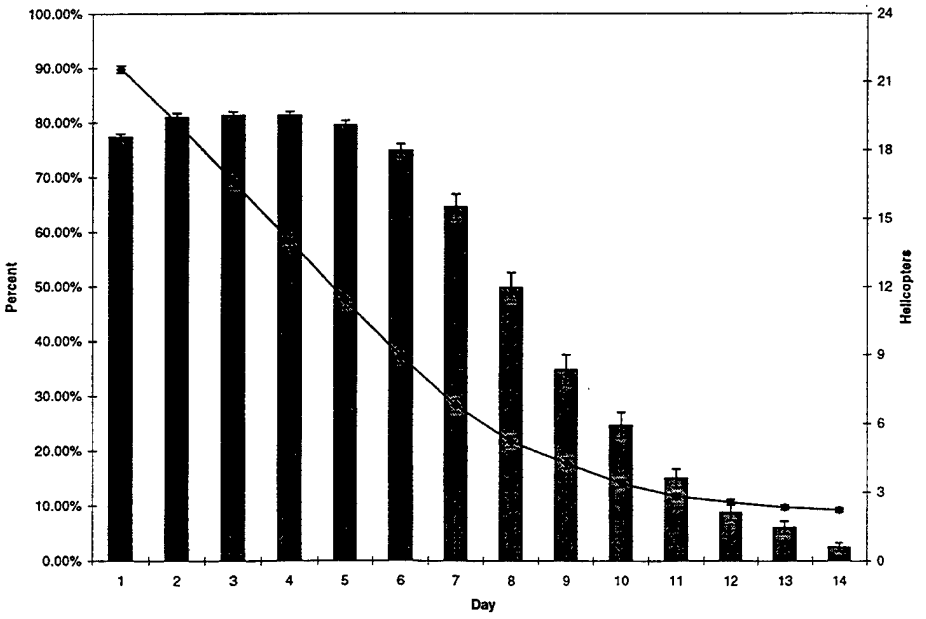

Figure 4. MOEs for a Weibull Distribution with a Shape of 1.0. Case II from Table 1 that shows the effects of a Weibull distribution with a shape parameter of 1.0 and a MTBMAF of 8.5 hours on the mean percent coverage and the mean number of surviving helicopters.

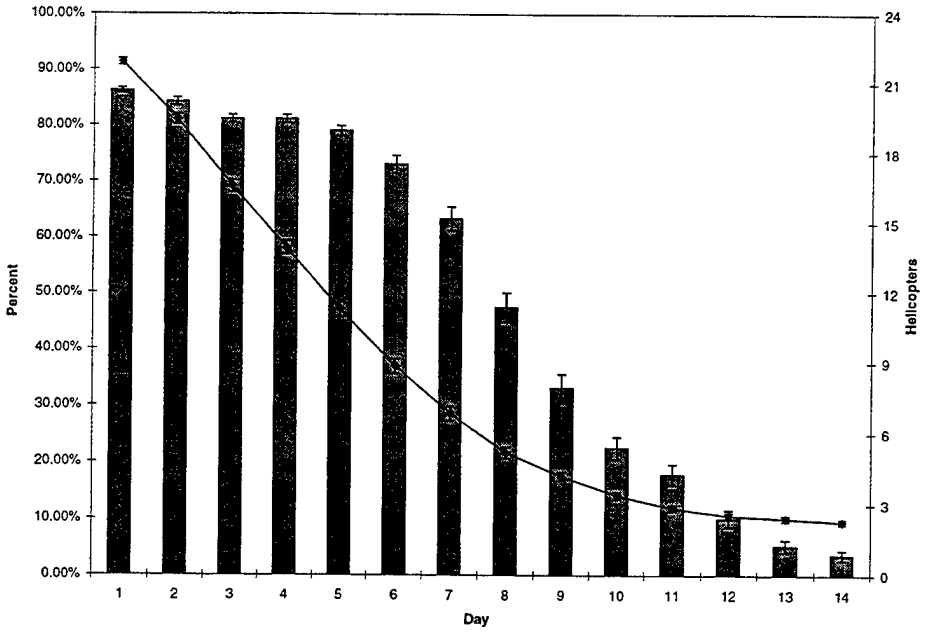

Figure 5. MOEs for a Weibull Distribution with a Shape of 2.0. Case III from Table 1 that shows the effects of a Weibull distribution with a shape parameter of 2.0 and a MTBMAF of 8.5 hours on the mean percent coverage and the mean number of surviving helicopters.

B. SENSITIVITY ANALYSIS FOR VULNERABILITY PARAMETERS

The vulnerability of the helicopters is modeled as an exponential random variable representing the mean time until a helicopter is shot down when in particular regions. The cases chosen for comparison are shown below in Table 2.

	Mean Time until a Helicopter is Shot Down while in a Low Vulnerability Region	Mean Time until a Helicopter is Shot Down while in a High Vulnerability Region
Case I	320 Hours	160 Hours
Case II	160 Hours	80 Hours
Case III	80 Hours	40 Hours

Table 2. Description of Vulnerability Cases for a Model with Exponential Times between Failures.

The other inputs, which remain constant, are as follows:

Numerical Illustration

⇒	24	Number of Helicopters
⇒	160	Speed of Helicopters (knots)
⇒	300	Time between Scheduled Maintenance Actions (flight hours)
⇒	1	Repair Facilities
⇒	1	Scheduled Maintenance Facilities
⇒	1	Mean Time to Repair a Failure (hours-Exponentially Distributed)
⇒	0.25	Mean Time of Helicopter Turnaround (hours-Exponentially Distributed)
⇒	144-192	Minimum/Maximum Time to Complete Scheduled Maintenance (hours-Uniformly Distributed)
⇒	8.5	Mean Time Between Mission-Affecting Failures (hours)
⇒	1.0	Shape of Weibull Distribution Modeling MAF
⇒	0.1	Probability of a failure being fatal (Crash)

One hundred runs of the simulation were conducted for a three-week campaign to observe the effects of the varying vulnerability rates on the mean percent coverage per day of the NAI as well as the mean number of helicopters surviving at the end of each day. Figure 6, Figure 7, and Figure 8 show how the mean coverage varied per day over the three-week period as well as the mean number of remaining helicopters at the end of each day. The results support what would be expected. As the vulnerability increases, the ability of the helicopters to maintain coverage decreases, along with the mean number of surviving helicopters for each day. With the low vulnerability rate, the helicopters are nearly able to maintain mean coverage of the NAI above 50% for almost two weeks. With the medium vulnerability rate, the helicopters can no longer maintain mean coverage of the NAI above 50% after ten days. With the high vulnerability rate, the helicopters are only able to maintain mean coverage above 50% for seven days. This emphasizes the fact that sufficient helicopters are necessary to sustain a prolonged operation, or that operational action by Blue is essential to successfully suppress enemy

(Red) defensive actions. It also informs T&E decision-makers that the vulnerability of the helicopters is a significant issue that dramatically affects the MOEs and needs to be carefully and thoroughly considered during operational field-testing.

As the vulnerability increases, the rate of decrease in the number of helicopters surviving increases as the time progresses since fewer helicopters are available to perform the mission. This causes the remaining helicopters to fly more missions and reach their scheduled maintenance flight hour limit sooner than normal. The helicopters are then temporarily no longer flying, but rather waiting in the scheduled maintenance queue. This pattern will continue unless the scheduled maintenance duration (overhaul time) is deliberately shortened or eliminated. In that case, the increasing occurrence of random failures will rapidly degrade coverage of the NAI.

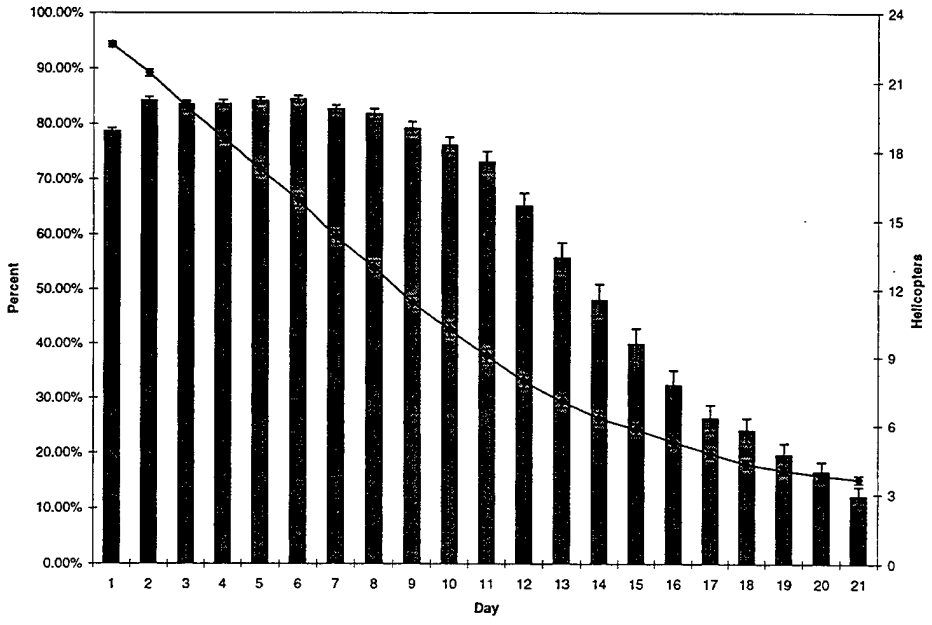

Figure 6. MOEs with Low Vulnerability for a Model with Exponential Times between Failures. Case I from Table 2 showing the effects of a low vulnerability rate on the mean percent coverage and the mean number of surviving helicopters.

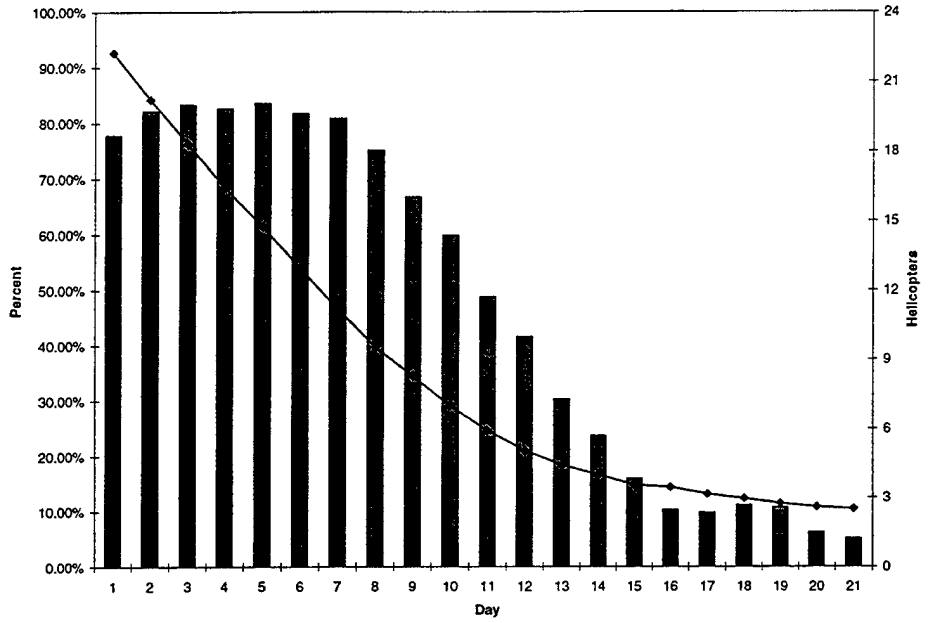

Figure 7. MOEs with Medium Vulnerability for a Model with Exponential Times between Failures. Case II from Table 2 showing the effects of a medium vulnerability rate on the mean percent coverage and the mean number of helicopters surviving.

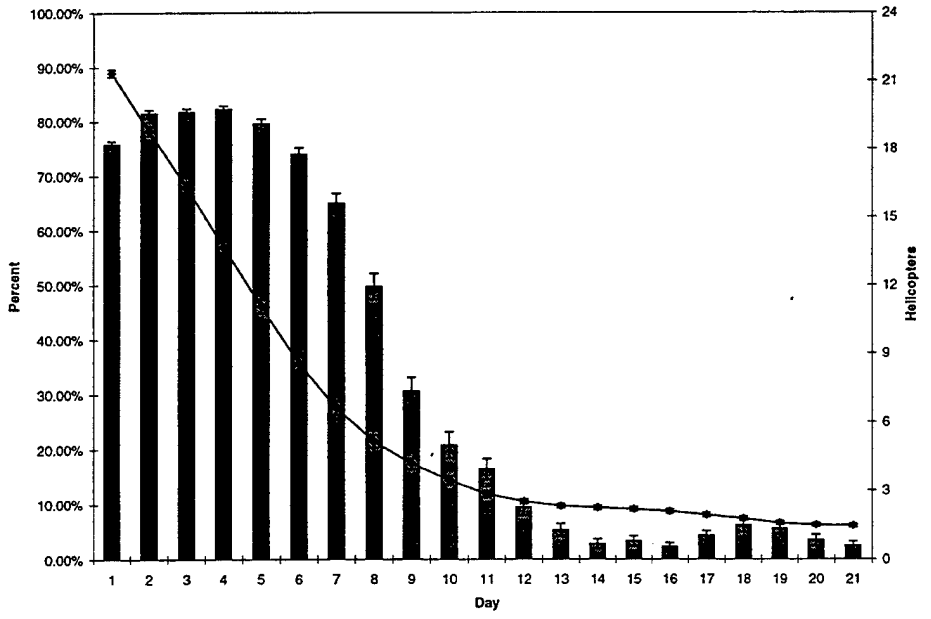

Figure 8. MOEs with High Vulnerability for a Model with Exponential Times between Failures. Case III from Table 2 showing the effects of a high vulnerability rate on the percent coverage and the number of helicopters surviving.

C. SENSITIVITY ANALYSIS FOR TIME BETWEEN SCHEDULED MAINTENANCE ACTIONS

The time between scheduled maintenance actions is the number of flight hours, T_S, which a helicopter accumulates before being overhauled. Recall the initial flight hours for each helicopter are staggered to allow a sequential progression of helicopters into the scheduled maintenance facility. As the time between scheduled maintenance actions is adjusted, so too is the staggering of the individual helicopter's flight hours. For each case examined, the initial stagger between each helicopter's flight hours is the time between scheduled maintenance actions divided by the number of helicopters. The cases chosen for comparison are shown below in Table 3.

	Time between Scheduled Maintenance Actions
Case I	300 Hours
Case II	400 Hours
Case III	500 Hours

Table 3. Description of Different Maintenance Policies for a Model with Exponential Times between Failures.

The other inputs, which remain constant, are as follows:

Numerical Illustration

⇒	24	Number of Helicopters
⇒	160	Speed of Helicopters (knots)
⇒	40	High-Threat Vulnerability (Mean Time until a Helicopter is Shot Down in Region) (hours)
⇒	80	Low-Threat Vulnerability (Mean Time until a Helicopter is Shot Down in Region) (hours)
⇒	1	Repair Facilities
⇒	1	Scheduled Maintenance Facilities
⇒	1	Mean Time to Repair a Failure (hours-Exponentially Distributed)
⇒	0.25	Mean Time of Helicopter Turnaround (hours-Exponentially Distributed)
⇒	144-192	Minimum/Maximum Time to Complete Scheduled Maintenance (hours-Uniformly Distributed)
⇒	8.5	Mean Time between Mission-Affecting Failures (hours)
⇒	1.0	Shape of Weibull Distribution Modeling MAF
⇒	0.1	Probability of a failure being fatal (Crash)

One hundred runs of the simulation were conducted for a two-week campaign to observe the effects of the different maintenance policies on the MOEs. Figure 9, Figure 10, and Figure 11 show the results of the varying maintenance policies. The only significant differences between the cases are between the 300-hour and 500-hour maintenance policies about halfway through the campaign. The longer time between maintenance actions allows for a slightly higher mean percentage of coverage for the 7^{th}, 8^{th} and 9^{th} days. This results from the helicopters flying more missions before reaching their flight hour limit for scheduled maintenance. By being able to continue flying for longer periods of time, the helicopters are able to maintain a higher mean percent coverage of the NAI. This ability to continue flying longer is also detrimental to the helicopters. While the helicopters are flying, they are still experiencing failures, some of which are fatal, as well as being subjected to enemy fires. This additional flight time causes the loss of more helicopters and hence the longer maintenance policy ends the

campaign with fewer helicopters than the shorter maintenance policies. The shorter maintenance policies force the helicopters to reach their flight hour limit for scheduled maintenance sooner and are forced to end the campaign on the ground waiting for scheduled maintenance. The establishment of an intelligently adaptable maintenance schedule is an open problem.

In the model as implemented, the rate at which helicopters are killed dominates all other factors. This dominant effect may be masking other outcomes of interest. Keeping this in mind, the results attributed to the change in maintenance policies may be more pronounced or significant for a lower vulnerability rate. Effort spent decreasing the attrition rate should be well rewarded.

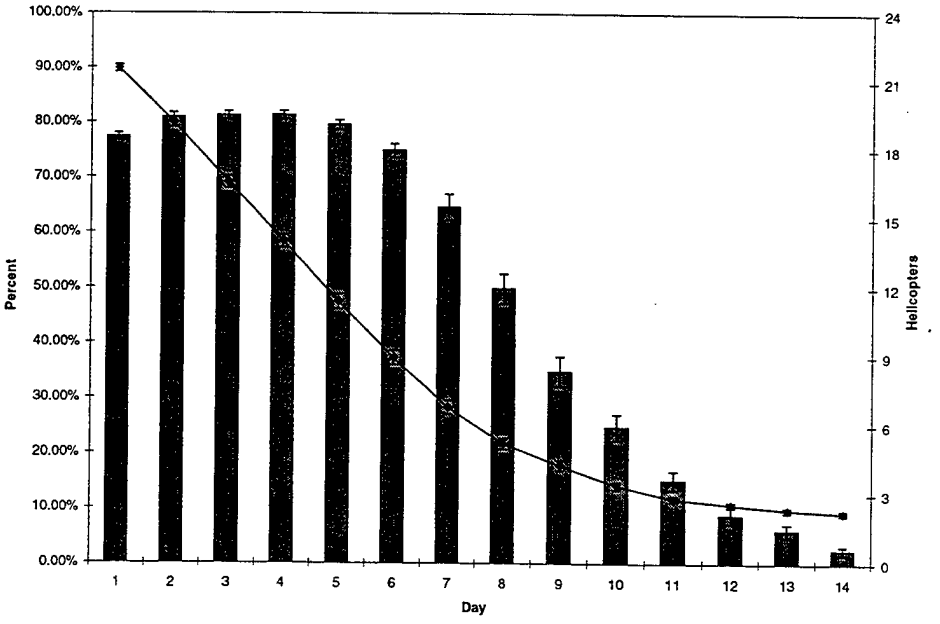

Figure 9. MOEs for 300-hour Maintenance Policy for Model with Exponential Time between Failures. Case I from Table 3 that shows the effects of 300 hours between scheduled maintenance activities on the mean percent coverage and the mean number of helicopters surviving.

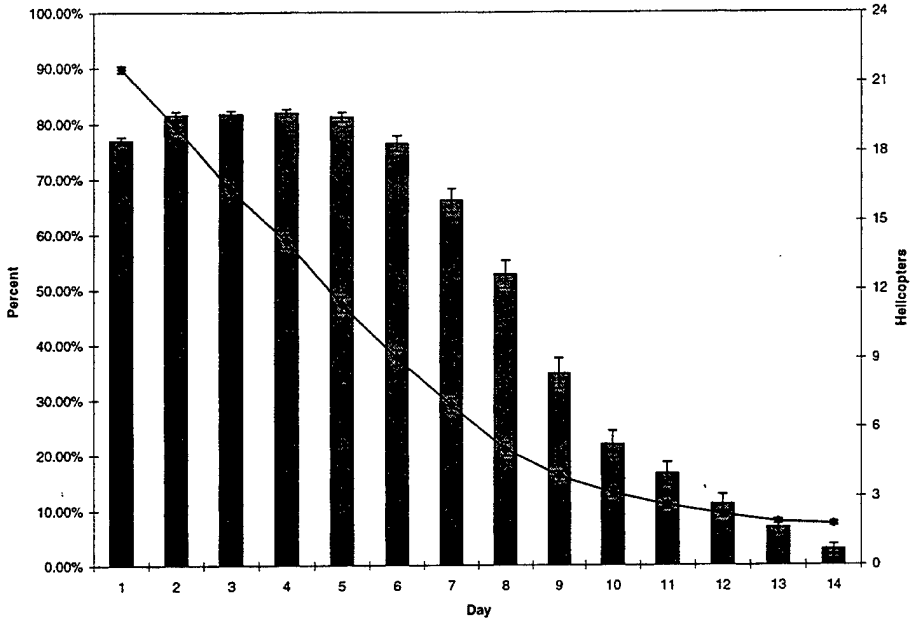

Figure 10. MOEs for 400-Hour Maintenance Policy for Model with Exponential Time between Failures. Case II from Table 3 that shows the effects of 400 hours between scheduled maintenance activities on the mean percent coverage and the mean number of helicopters surviving.

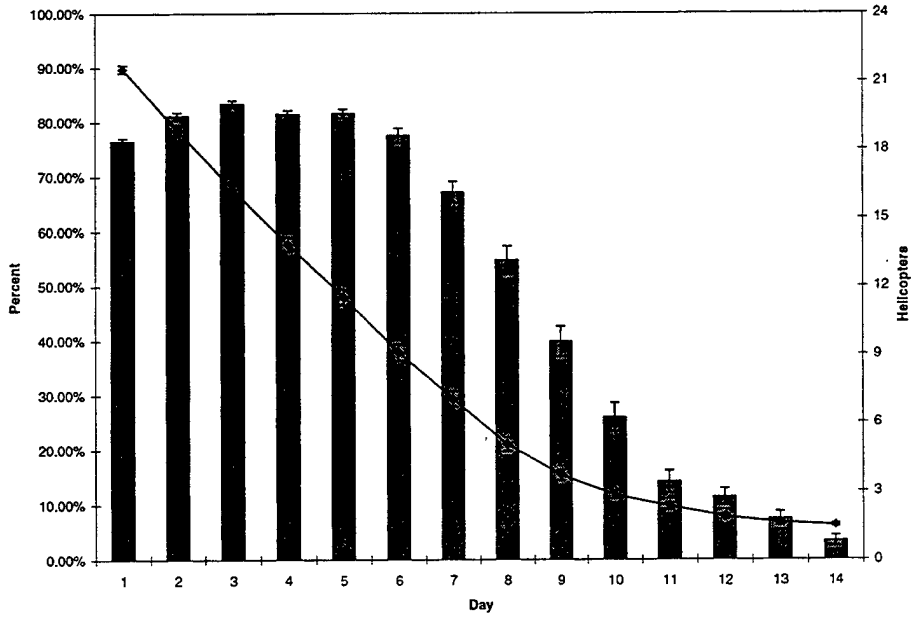

Figure 11. MOEs for 500-Hour Maintenance Policy for Model with Exponential Times between Failures. Case III from Table 3 that shows the effects of 500 hours between scheduled maintenance activities on the mean percent coverage and the mean number of helicopters surviving.

D. SENSITIVITY ANALYSIS FOR MEAN TIMES BETWEEN MISSION-AFFECTING FAILURES

This section examines the effect that different mean times between mission-affecting failures have on the MOEs. The cases chosen for comparison are shown below in Table 4.

	Shape	Scale	Mean Time between Mission-Affecting Failures
Case I	1.0	4.25	4.25 Hours
Case II	1.0	8.5	8.5 Hours
Case III	1.0	17.0	17.0 Hours

Table 4. Description of MTBMAF for Model with Exponential Times between Failures.

The other inputs, which remain constant, are as follows:

Numerical Illustration

⇒	24	Number of Helicopters
⇒	160	Speed of Helicopters (knots)
⇒	300	Time between Scheduled Maintenance Actions (flight hours)
⇒	40	High-Threat Vulnerability (Mean Time until a Helicopter is Shot Down in Region) (hours)
⇒	80	Low-Threat Vulnerability (Mean Time until a Helicopter is Shot Down in Region) (hours)
⇒	1	Repair Facilities
⇒	1	Scheduled Maintenance Facilities
⇒	1	Mean Time to Repair a Failure (hours-Exponentially Distributed)
⇒	0.25	Mean Time of Helicopter Turnaround (hours-Exponentially Distributed)
⇒	144-192	Minimum/Maximum Time to Complete Scheduled Maintenance (hours-Uniformly Distributed)
⇒	0.1	Probability of a failure being fatal (Crash)

One hundred runs of the simulation were conducted for a two-week campaign to observe the effects of the different MTBMAF on the MOEs. Figure 12, Figure 13, and Figure 14 show the results for each of the different MTBMAF. The mean time between mission-affecting failures has a significant effect on both the mean percent coverage of

the NAI per day and the mean number of helicopters surviving at the end of each day. As the MTBMAF increases, on the average fewer failures are experienced during the campaign, which results in several areas of performance in the system improving. With fewer failures, more helicopters are able to successfully complete an entire mission without having to return to home base for repairs. This results in more and longer times on station for each helicopter pair, thus improving the mean percent coverage of the Named Area of Interest. However, more helicopters are subject to enemy action. The diminished mean number of failures also results in less time being spent in the repair facility and more helicopters being available to perform the assigned mission. Also as fewer failures are experienced, fewer crashes (modeled as 10% of the number of MAF) occur. This results in a lower total attrition rate for the helicopters during the campaign and significantly more helicopters surviving at the end of each day. Thus, the MTBMAF needs to be well estimated during actual field-testing, along with the shape of the time to failure. Note that the MTBMAF may well decrease during testing if failure modes are discovered and rectified.

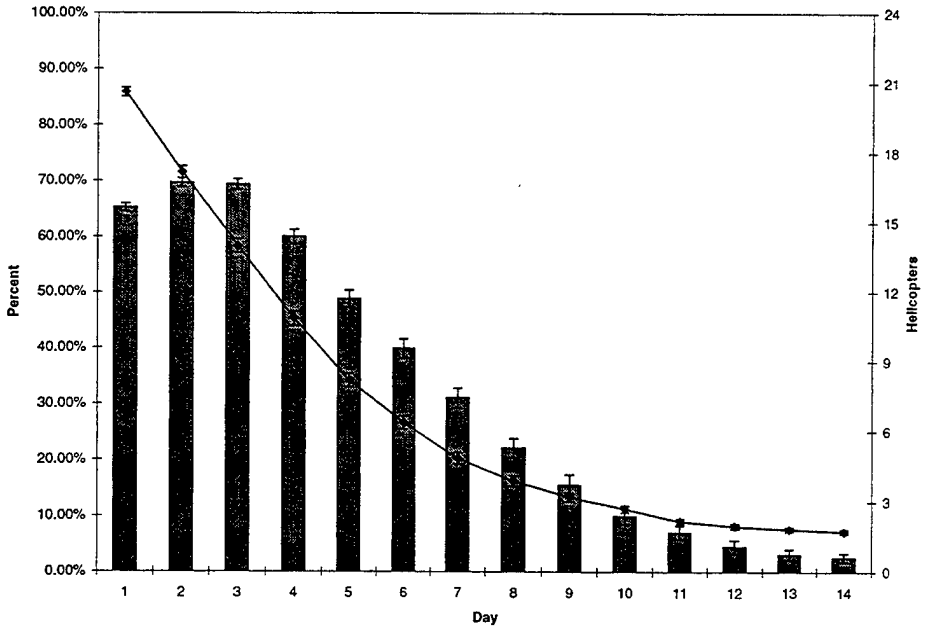

Figure 12. MOEs with MTBMAF equal to 4.25 Hours for Model with Exponential Times between Failures. Case I from Table 4 that shows the effect with a MTBMAF equal to 4.25 hours on the mean percent coverage and the mean number of helicopters surviving.

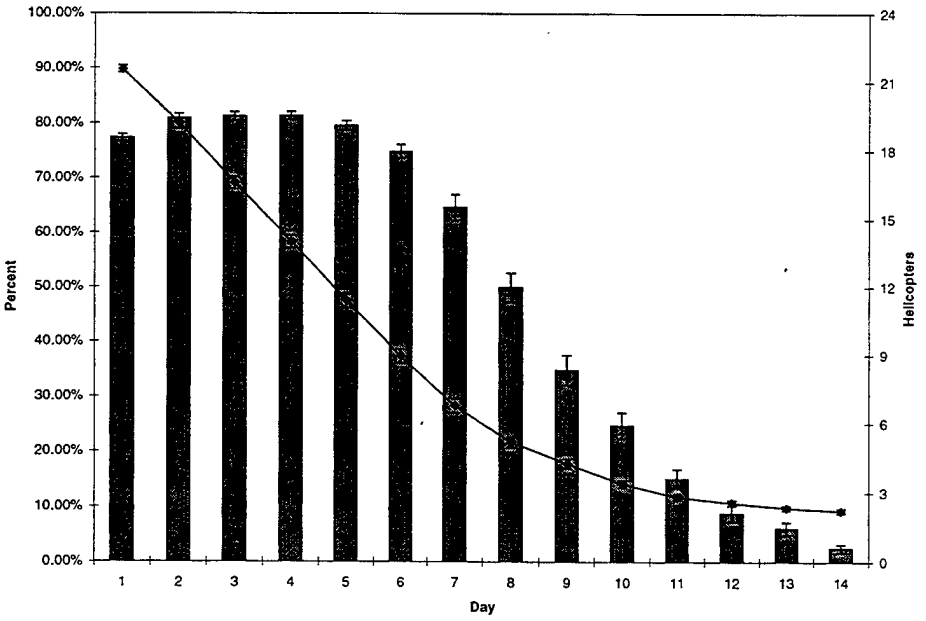

Figure 13. MOEs with MTBMAF equal to 8.5 Hours for Model with Exponential Times between Failures. Case II from Table 4 that shows the effect with MTBMFAF equal to 8.5 hours on the mean percent coverage and the mean number of helicopters surviving.

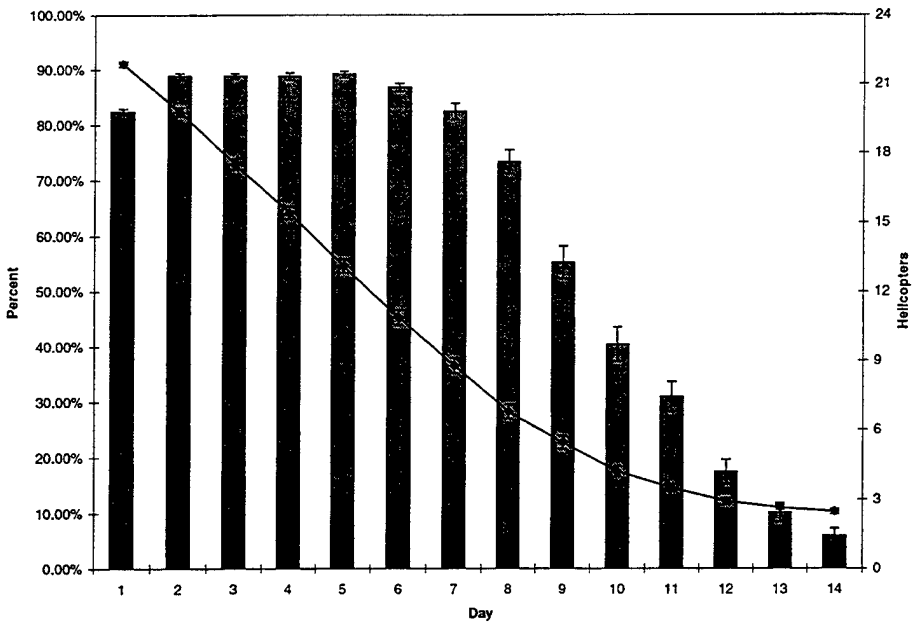

Figure 14. MOEs with MTBMAF equal to 17.0 Hours for Model with Exponential Times between Failures. Case III from Table 4 that shows the effect with MTBMAF equal to 17.0 hours on the mean percent coverage and the mean number of helicopters surviving.

E. SENSITIVITY ANALYSIS OF OVERHAUL TIMES

The overhaul time is that amount of time needed to complete scheduled maintenance on a helicopter and return it to service. It is being modeled with a uniform distribution that specifies the minimum and maximum times to complete the scheduled maintenance. This section examines the effects of different overhaul times on the MOEs. The cases selected for comparison are listed below in Table 5.

	Minimum Overhaul Time	Maximum Overhaul Time
Case I	48 Hours	96 Hours
Case II	96 Hours	144 Hours
Case III	144 Hours	192 Hours

Table 5. Description of Overhaul Times for Model with Exponential Times between Failures.

The other inputs, which remain constant, are as follows:

Numerical Illustration

⇒	24	Number of Helicopters
⇒	160	Speed of Helicopters (knots)
⇒	300	Time between Scheduled Maintenance Actions (flight hours)
⇒	40	High-Threat Vulnerability (Mean Time until a Helicopter is Shot Down in Region) (hours)
⇒	80	Low-Threat Vulnerability (Mean Time until a Helicopter is Shot Down in Region) (hours)
⇒	1	Repair Facilities
⇒	1	Scheduled Maintenance Facilities
⇒	1	Mean Time to Repair a Failure (hours-Exponentially Distributed)
⇒	0.25	Mean Time of Helicopter Turnaround (hours-Exponentially Distributed)
⇒	8.5	Mean Time between Mission-Affecting Failures (8.5 hours)
⇒	1.0	Shape for MTBMAF
⇒	0.1	Probability of a failure being fatal (Crash)

One hundred runs of the simulation were conducted for a two-week campaign to observe the effects of the different overhaul times on the MOEs. In each case, one scheduled maintenance facility was available for overhaul. There is also a separate facility to repair MAF and turn around helicopters. Figure 15, Figure 16, and Figure 17 show the results for the different overhaul times. The effect of the different overhaul times begins to show up after four days. The longer overhaul times result in fewer helicopters being available once they reach their flight hour limit since they are now sitting on the ground waiting for the maintenance facility to begin the overhaul. This results in fewer helicopters flying the assigned mission until each of their flight hour limits is reached, and thus less coverage of the NAI being provided. The longer overhaul times do result in more helicopters surviving at the end of the campaign. This is once again due to the helicopters being backed up in the maintenance facility, fewer helicopters flying missions, and thus fewer helicopter crashes and attrition.

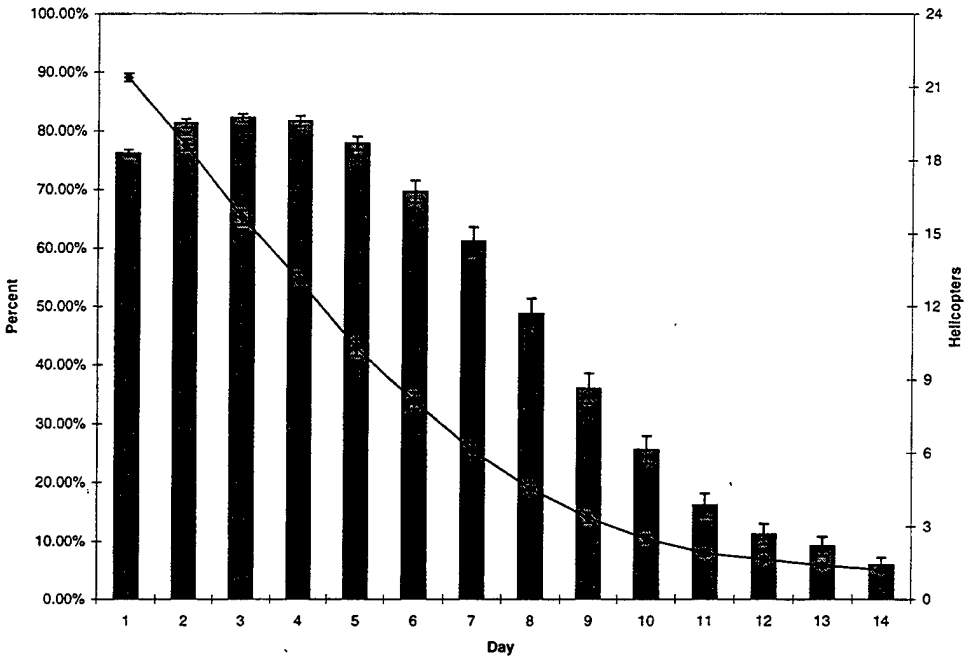

Figure 15. MOEs with Short Overhaul Times for Model with Exponential Times between Failures. Case I from Table 5 that shows the effects of a short overhaul time on the mean percent coverage and the mean number of helicopters surviving.

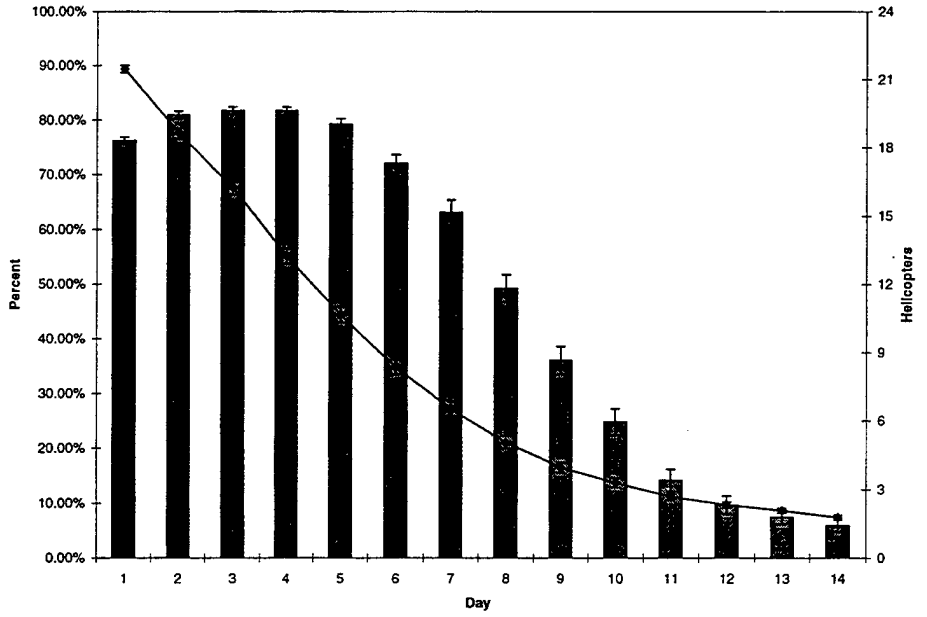

Figure 16. MOEs with Medium Overhaul Times for Model with Exponential Times between failures. Case II from Table 5 that shows the effects of a medium overhaul time on the mean percent coverage and the mean number of helicopters surviving.

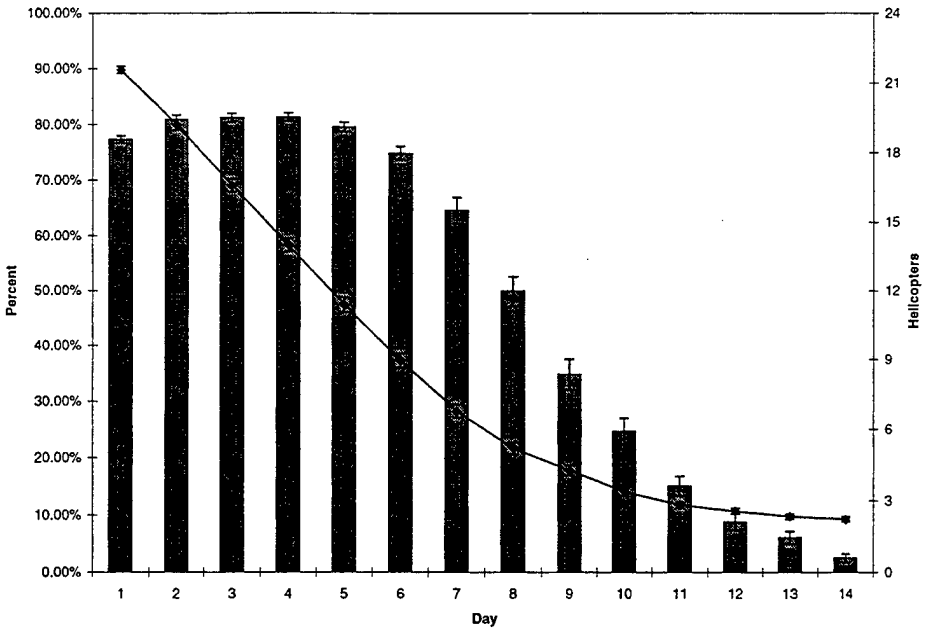

Figure 17. MOEs with Long Overhaul Times for Model with Exponential Times between Failures. Case III from Table 5 that shows the effects of long overhaul times on the mean percent coverage and the mean number of helicopters surviving.

F. SENSITIVITY ANALYSIS ON THE NUMBER OF SCHEDULED MAINTENANCE FACILITIES

This section examines the effect that different numbers of scheduled maintenance facilities have on the MOEs. Recall from Chapter 3, Section D on page 19 that the maintenance facility is utilized exclusively for scheduled overhaul maintenance. The cases chosen for consideration are shown below in Table 6.

	Number of Scheduled Maintenance Facilities
Case I	1
Case II	2
Case III	4

Table 6. Description of the Number of Scheduled Maintenance Facilities for Model with Exponential Times between Failures.

The other inputs, which remain constant, are as follows:

Numerical Illustration

⇒	24	Number of Helicopters
⇒	160	Speed of Helicopters (knots)
⇒	300	Time between Scheduled Maintenance Actions (flight hours)
⇒	40	High-Threat Vulnerability (Mean Time until a Helicopter is Shot Down in Region) (hours)
⇒	80	Low-Threat Vulnerability (Mean Time until a Helicopter is Shot Down in Region) (hours)
⇒	1	Repair Facilities
⇒	1	Mean Time to Repair a Failure (hours-Exponentially Distributed)
⇒	0.25	Mean Time of Helicopter Turnaround (hours-Exponentially Distributed)
⇒	8.5	Mean Time between Mission-Affecting Failures (8.5 hours)
⇒	1.0	Shape of Weibull Distribution Modeling MAF
⇒	144-192	Minimum/Maximum Time to Complete Scheduled Maintenance (Uniformly Distributed)
⇒	0.1	Probability of a failure being fatal (Crash)

One hundred runs of the simulation were conducted for a two-week campaign to observe the effects of the different number of scheduled maintenance facilities on the MOEs. Figure 18, Figure 19, and Figure 20 show the results for each of the different cases. The results show that as the number of scheduled maintenance facilities increases, the helicopters are able to maintain a higher mean percentage of coverage later in the campaign. In the short term, the number of maintenance facilities has very little effect. As time progresses and more helicopters are sent in for overhaul, the number of scheduled maintenance facilities has a large impact. On the last day of the campaign, mean coverage more than doubled from 2.5% with one scheduled maintenance facility to over 8% percent for just one additional facility and to better than 10% with an additional three facilities. This does take a toll on the number of helicopters remaining at the end of the campaign since fewer helicopters will be waiting in the maintenance facilities and

more are returned to conduct the assigned mission in a timely manner. These helicopters are once again subjected to attrition from enemy action and can also crash.

If these effects are to be seen during actual testing, the tests will need to be of longer duration, and tests cannot be conducted with helicopters that have all just completed an overhaul. The helicopters used in the operational tests should be similar to those used in the field, which have staggered flight hours to facilitate staggered overhauls.

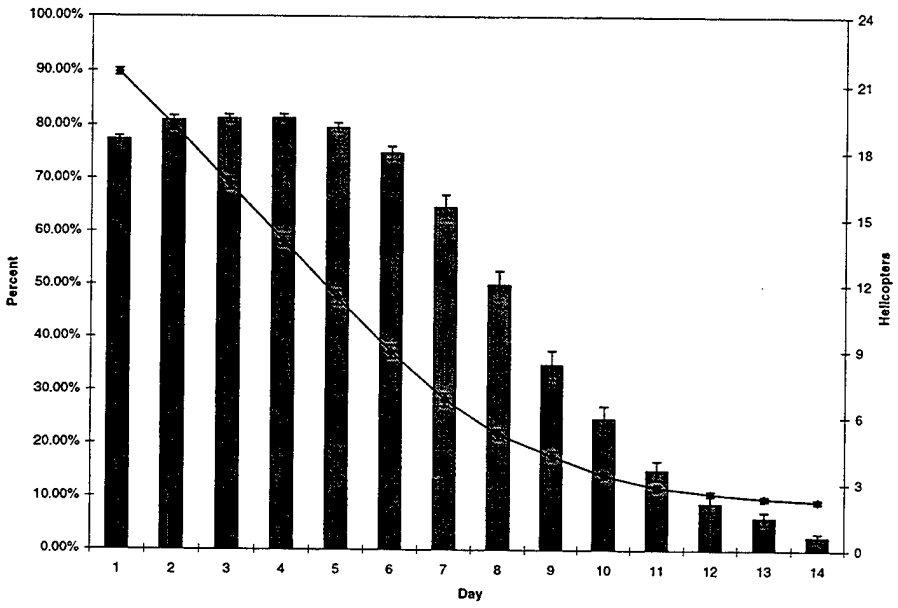

Figure 18. MOEs with One Scheduled Maintenance Facility for Model with Exponential Times between Failures. Case I from Table 6 that shows the effects of one scheduled maintenance facility on the mean percent coverage and the number of helicopters surviving.

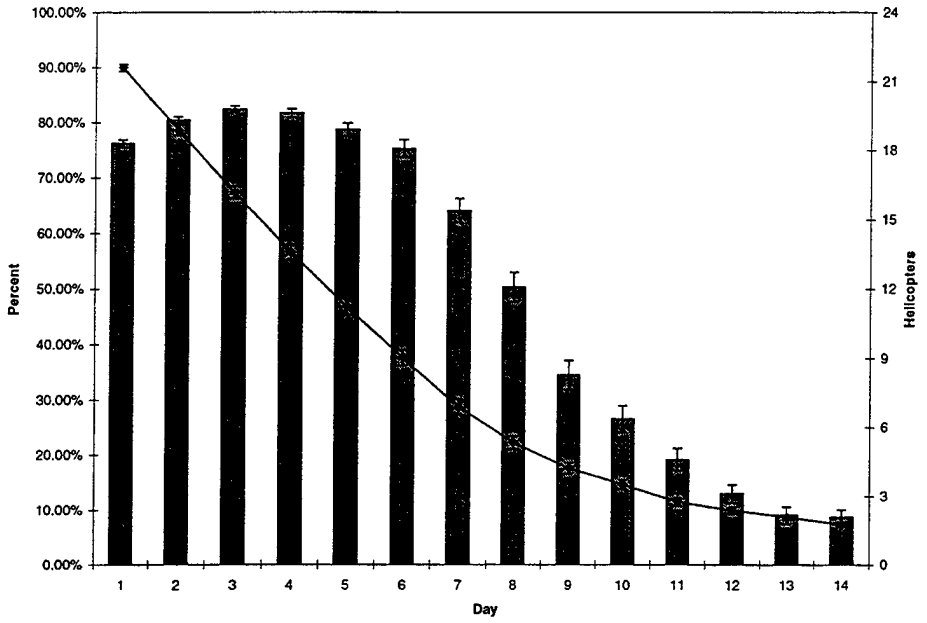

Figure 19. MOEs with Two Scheduled Maintenance Facilities for Model with Exponential Times between Failures. Case II from Table 6 that shows the effects of two scheduled maintenance facilities on the mean percent coverage and the number of helicopters surviving.

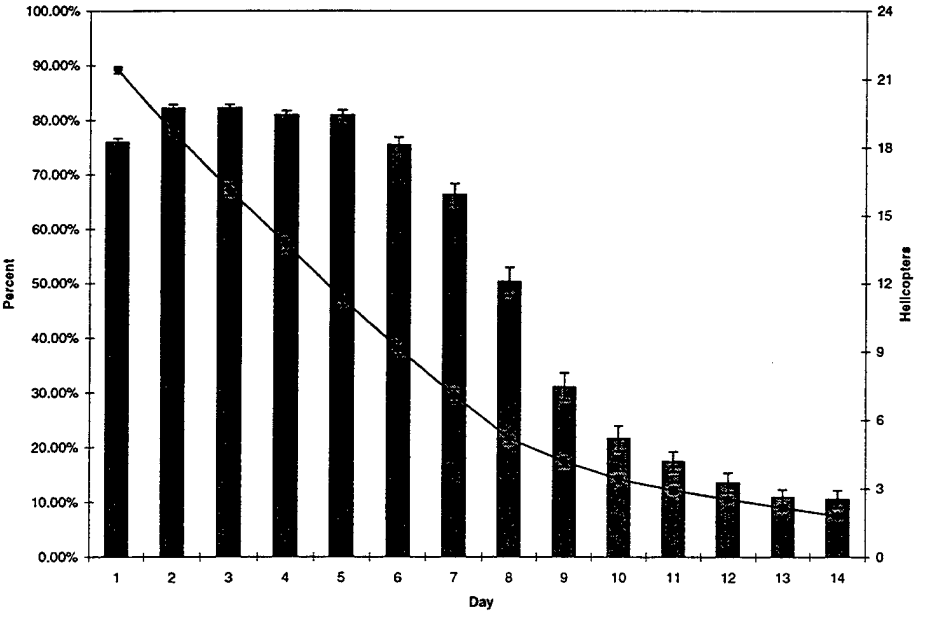

Figure 20. MOEs with Four Scheduled Maintenance Facilities for Model with Exponential Times between Failures. Case III from Table 6 that shows the effects of four scheduled maintenance facilities on the mean percent coverage and the mean number of helicopters surviving.

G. SENSITIVITY ANALYSIS FOR THE NUMBER OF REPAIR FACILITIES

This section examines the effect that different numbers of repair facilities have on the MOEs. Recall from Chapter 3, Section D on page 19 that the repair facility is used exclusively for repair of random mission-affecting failures and helicopter rearming and refueling. The repair facilities operate on the basis of priority maintenance in which the helicopter in the repair facility with the shortest repair time will be serviced first. The cases selected are shown below in **Table 7.**

	Number of Repair Facilities
Case I	1
Case II	2
Case III	4

Table 7. Description of the Number of Repair Facilities for Model with Exponential Times between Failures.

The other inputs, which remain constant, are as follows:

Numerical Illustration

⇒	24	Number of Helicopters
⇒	160	Speed of Helicopters (knots)
⇒	300	Time between Scheduled Maintenance Actions (flight hours)
⇒	40	High-Threat Vulnerability (Mean Time until a Helicopter is Shot Down in Region) (hours)
⇒	80	Low-Threat Vulnerability (Mean Time until a Helicopter is Shot Down in Region) (hours)
⇒	1	Scheduled Maintenance Facilities
⇒	1	Mean Time to Repair a Failure (hours-Exponentially Distributed)
⇒	0.25	Mean Time of Helicopter Turnaround (hours-Exponentially Distributed)
⇒	8.5	Mean Time between Mission-Affecting Failures (hours)
⇒	1.0	Shape of Weibull Distribution Modeling MAF
⇒	144-192	Minimum/Maximum Time to Complete Scheduled Maintenance (hours-Uniformly Distributed)
⇒	0.1	Probability of a failure being fatal (Crash)

One hundred runs of the simulation were conducted for a two-week campaign to observe the effects of the different number of repair facilities on the MOEs. Figure 21, Figure 22, and Figure 23 show the results for each of the different numbers. The results show that the number of repair facilities has little effect on either of the MOEs. This is the result of there being a sufficient number of helicopters at the beginning of the campaign to overcome any delays in the repair facilities. Even if the single repair facility case has a queue of helicopters, it is able to complete the repairs before the repair backlog causes a detrimental problem.

The reader is cautioned that for the parameters chosen for these cases, the repair facilities were never challenged. For the 3 cases observed, the mean number of non-fatal mission-affecting failures experienced per campaign was 72.42. This means that on average there were approximately 5.17 MAF that needed to be repaired per day. Using the mean time to repair of 1.0 hours, the repair facility was busy repairing a mission-affecting failure on average just over 5 hours per day. The average time needed to rearm and refuel all 24 helicopters using a mean turnaround time of 0.25 hours is 6 hours. Even if all 24 helicopters need to be reamed and refueled on any given day, the average time that the repair facility is busy is just over 11 hours per day.

The cases analyzed are far from stretching the limits of one repair facility, let alone two or four. More analysis needs to be done in this area by looking at longer repair times, fewer helicopters, or a completely different distribution for the repair times. In these cases reduction in force size of one or two helicopters being in the repair facility may dramatically affect the MOEs.

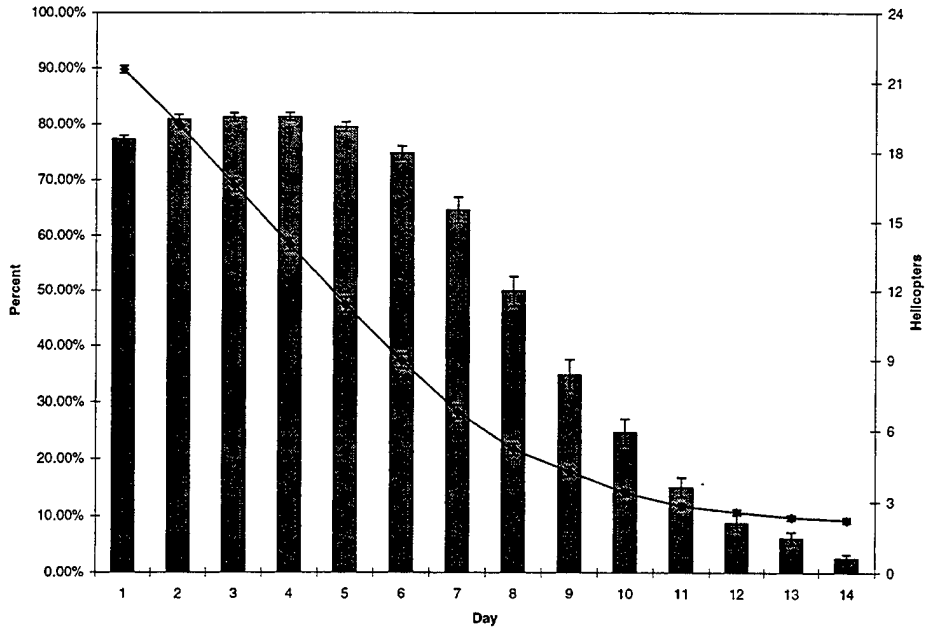

Figure 21. MOEs with a Single Repair Facility for Model with Exponential Times between Failures. Case I from Table 7 that shows the effects of a single repair facility on the mean percent coverage and the mean number of helicopters surviving.

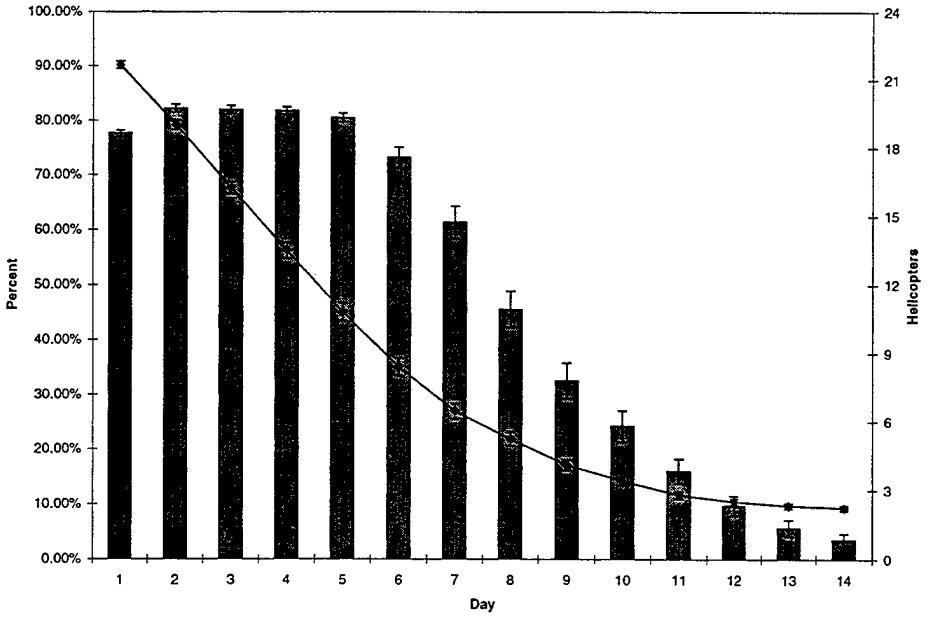

Figure 22. MOEs with Two Repair Facilities for Model with Exponential Times between Failures. Case II from Table 7 that shows the effects of two repair facilities on the mean percent coverage and the mean number of helicopters surviving.

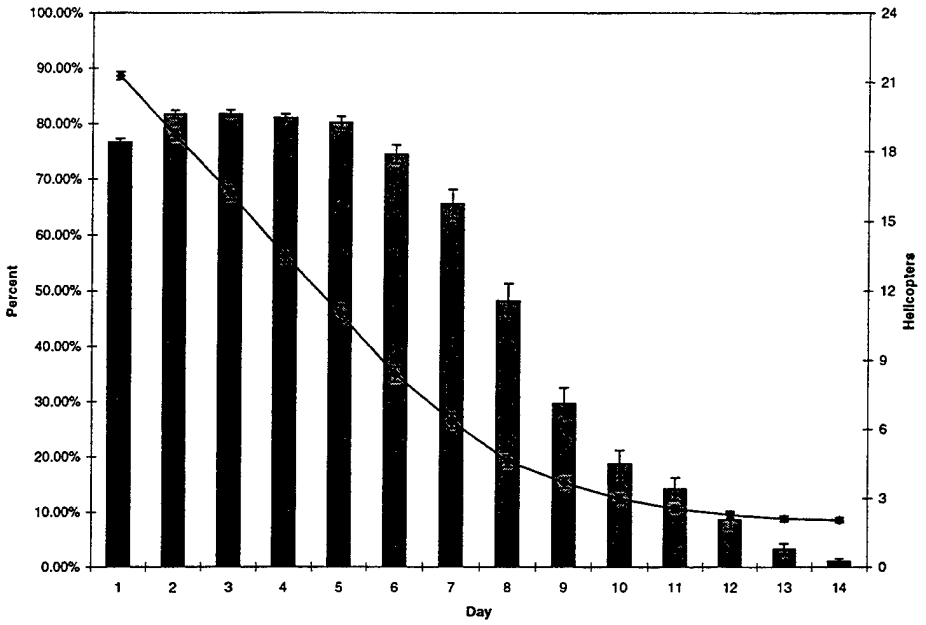

Figure 23. MOEs with Four Repair Facilities for Model with Exponential Times between Failures. Case III from Table 7 that shows the effects of four repair facilities on the mean percent coverage and the mean number of helicopters surviving.

H. SENSITIVITY ANALYSIS FOR PRIORITY MAINTENANCE

Priority maintenance is the maintenance policy of determining the helicopter in the repair queue with the shortest repair time and conducting repairs on this helicopter first. If the priority maintenance policy is not in effect, the repair system operates on a first-come, first-served, basis. This section examines the effects of the two different maintenance policies on the MOEs. The cases chosen for consideration are shown below in Table 8.

	Priority Maintenance
Case I	TRUE
Case II	FALSE

Table 8. Description of Priority Maintenance Policies for Model with Exponential Times between Failures.

The other inputs, which remain constant, are as follows:

Numerical Illustration

⇒	24	Number of Helicopters
⇒	160	Speed of Helicopters (knots)
⇒	300	Time between Scheduled Maintenance Actions (flight hours)
⇒	40	High-Threat Vulnerability (Mean Time until a Helicopter is Shot Down in Region) (hours)
⇒	80	Low-Threat Vulnerability (Mean Time until a Helicopter is Shot Down in Region) (hours)
⇒	2	Scheduled Maintenance Facilities
⇒	2	Repair Facilities
⇒	1	Mean Time to Repair a Failure (hours-Exponentially Distributed)
⇒	0.25	Mean Time of Helicopter Turnaround (hours-Exponentially Distributed)
⇒	8.5	Mean Time between Mission-Affecting Failures (hours)
⇒	1	Shape of Weibull Distribution Modeling MAF
⇒	144-192	Minimum/Maximum Time to Complete Scheduled Maintenance (hours-Uniformly Distributed)
⇒	0.1	Probability of a failure being fatal (Crash)

One hundred runs of the simulation were conducted for a two-week campaign to observe the effects of the different maintenance policies on the MOEs. Figure 47 and Figure 48 show the results for each of the different policies. As expected from the previous section, there is very little difference between the results for the two different maintenance policies. The mean numbers of surviving helicopters are comparable throughout the campaign, as is the mean percent coverage per day of the NAI. There is essentially no difference between the two policies as far as the two observed MOEs are concerned since the repair facilities are not saturated.

As previously discussed in Section G on page 46 the cases analyzed do not test the repair facilities to its limits. Here again the repair facility spends on average just over 5 hours per day performing repairs. In order to see the effects of priority maintenance, the repair facility must first be tested near its limits. This can be accomplished by increasing

the number of failures or by increasing the average amount of time necessary to complete a repair of a mission-affecting failure.

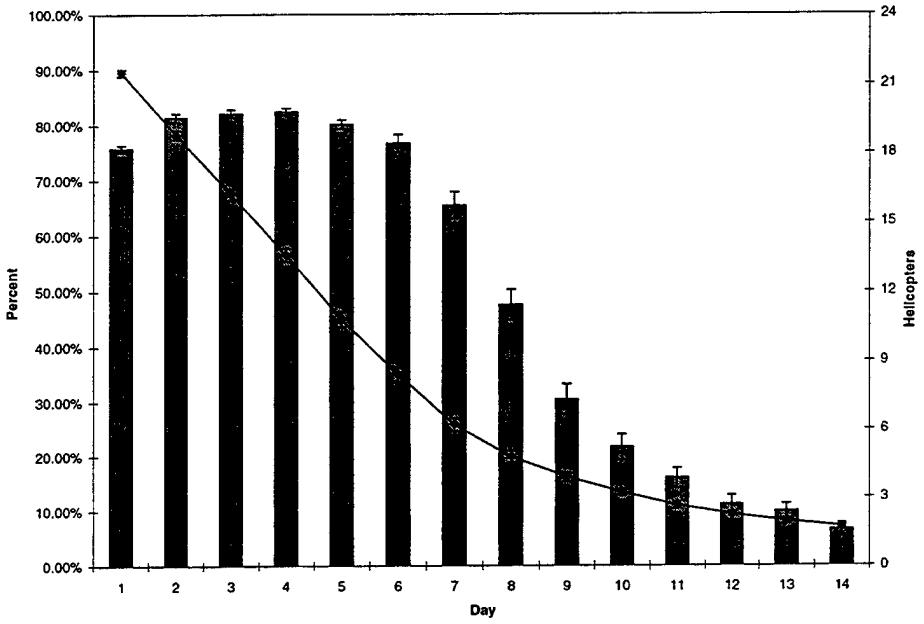

Figure 24. MOEs with Priority Maintenance for Model with Exponential Times between Failures. Case I from Table 8 that shows the effects of priority maintenance on the mean percent coverage and the mean number of helicopters surviving.

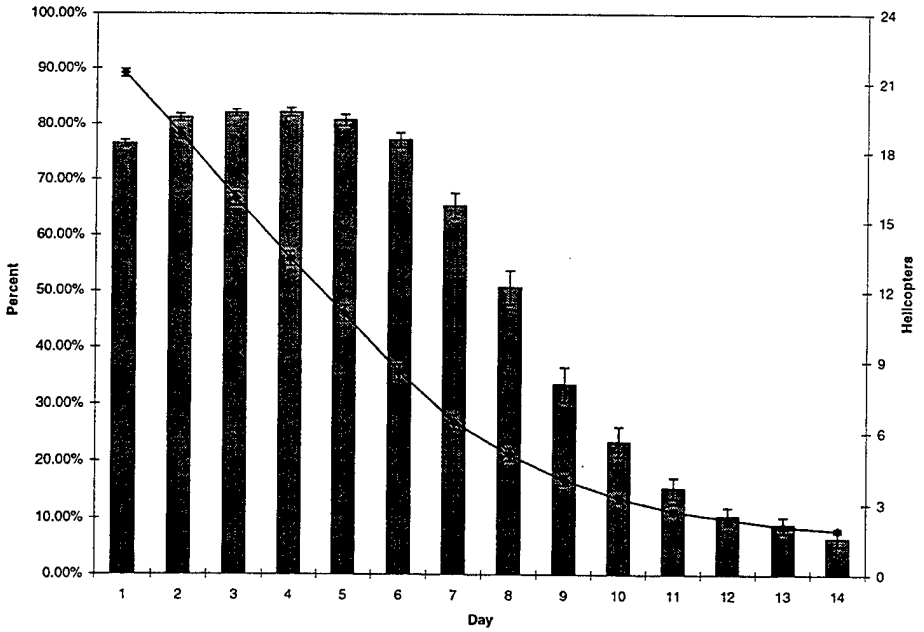

Figure 25. MOEs with First-Come, First-Served, Maintenance for Model with Exponential Times between Failures. Case II from Table 8 that shows the effects of non-priority maintenance on the mean percent coverage and the number of helicopters surviving.

I. SUMMARY OF ANALYSIS FOR THE WEIBULL DISTRIBUTION

This chapter focused on the behavior of the MOEs when the Weibull distribution was used as the underlying distribution for the mean time between mission-affecting failures. The dominant sensitivities, as determined by the simulation, were the vulnerability rates for each region, the mean time between mission-affecting failures, and *the shape of the distribution.* The shape of the distribution can be thought of as representing the type of failures ("infant mortality" or "wearout" or other) that tend to occur. This indicates that the types of failures experienced are just as important as the mean time between mission-affecting failures. The vulnerability rates for each area had a large effect on the MOEs. This indicates that the vulnerability of the helicopter must be

analyzed to minimize its effects on mission accomplishment. Vulnerability can possibly be managed by tactics. Loss of sensor capability may well increase vulnerability.

V. MODELING SYSTEM AGING AND SCHEDULED MAINTENANCE

In this chapter a non-homogeneous increasing-rate Poisson process is used to model the rate of occurrence of mission-affecting failures (MAF) when *aging* is assumed (failures, predominantly of the platform, occur more frequently as time elapses) (Ross, 1997). The following specific and convenient (but only illustrative) intensity function for the non-homogeneous Poisson process is used:

$$\lambda(t) = \lambda_1 + \lambda_2 (p+1) t^p \text{ , where } p = 1 \qquad \text{(V-1)}$$

The mean value function for the non-homogeneous Poisson process is:

$$\Lambda(t) = \lambda_1 t + \lambda_2 t^{(p+1)} \qquad \text{(V-2)}$$

The average time between mission-affecting failures (ATBMAF) is approximated by dividing the specified time between scheduled maintenance actions, denoted by T_S and taken as fixed, by the expected number of failures to occur in the time between scheduled maintenance actions, as shown below.

$$ATBMAF = \frac{T_s}{\lambda_1 T_s + \lambda_2 T_s^2} = \frac{1}{\lambda_1 + \lambda_2 T_s} \qquad \text{(V-3)}$$

This formula shows that the average rate of failure occurrence, $(ATBMAF)^{-1}$, increases (linearly) with time. The parameters for the ATBMAF are chosen by setting T_S equal to the time between scheduled maintenance actions, setting the ATBMAF to a specified level, and then fixing one of the parameters to solve for the other parameter.

The non-homogenous Poisson failure process used provides the analyst and planner the ability to understand the possible effects of aging on the helicopters. As the helicopters age (more flight hours) the times between mission-affecting failures tend to decrease. This means that the helicopters generally will have more mission-affecting failures just prior to entering scheduled maintenance than they will have upon exiting scheduled maintenance. The model, utilizing the non-homogeneous Poisson failure process, has been set up to provide helicopters that are "as good as new" upon completing an overhaul (there is no post-overhaul infant failure, although this is a practical possibility). The model also is set up to reflect imperfect repairs. This means that when a helicopter completes repair of a non-scheduled random failure, a new independent failure time is not generated. Rather, the time until its next failure is carried forward from its previous generated failure time, *unless* the helicopter has just completed scheduled maintenance.

The model also makes the assumption that the initial flight hours for each helicopter are staggered so that the helicopters sequentially and periodically enter the scheduled maintenance facility as discussed in Chapter 3, Section D on page 19.

The MOEs displayed in this chapter are again the mean percent coverage per day of the NAI and the mean number of helicopter surviving at the end of each day. The 25^{th}, 50^{th}, and 75^{th} percentiles for each of the MOEs appear in Appendix C. Appendix C also displays for a campaign the mean number of MAF, mean number of fatal failures, and mean number of helicopters shot down. The mean repair and turnaround time, mean number of missions started, probability of returning to base safely, mean time spent in the

high threat regions, mean survival time of individual helicopters, and the mean number of helicopters in the repair system for each campaign are also displayed in Appendix C.

A. SENSITIVITY ANALYSIS FOR VULNERABILITY PARAMETERS

The vulnerability of the helicopters is again modeled as an exponential random variable specified by the mean time until a helicopter is shot down when in particular regions. Note that the reduction of threat to helicopters by pausing to fire back is *not* represented here. This tactic may be very profitable, and should be modeled in follow-on work. The cases chosen for comparison are shown below in Table 9.

	Mean Time until a Helicopter is Shot Down while in a Low Vulnerability Region	Mean Time until a Helicopter is Shot Down while in a High Vulnerability Region
Case I	320 Hours	160 Hours
Case II	160 Hours	80 Hours
Case III	80 Hours	40 Hours

Table 9. Description of Vulnerability Cases for Model with a Non-homogeneous Failure Rate Process.

The other inputs, which remain constant, are as follows:

Numerical Illustration

⇒	24	Number of Helicopters
⇒	160	Speed of Helicopters (knots)
⇒	300	Time between Scheduled Maintenance Actions (flight hours)
⇒	1	Repair Facilities
⇒	1	Scheduled Maintenance Facilities
⇒	1	Mean Time to Repair a Failure (hours-Exponentially Distributed)
⇒	0.25	Mean Time of Helicopter Turnaround (hours-Exponentially Distributed)
⇒	144-192	Minimum/Maximum Time to Complete Scheduled Maintenance (hours-Uniformly Distributed)
⇒	0.1	λ_1 (Average Time between Mission-Affecting Failures = 8.5 hours)
⇒	5.8824e-5	λ_2 (Average Time between Mission-Affecting Failures = 8.5 hours)
⇒	0.1	Probability of a failure being fatal (Crash)

One hundred runs of the simulation were conducted for a three-week campaign to observe the effects of the varying vulnerability rates on the mean percent coverage per day of the NAI as well as the mean number of helicopters surviving at the end of each day. Figure 26, Figure 27, and Figure 28 graphically show how the mean coverage varied per day over the three-week period as well as the mean number of remaining helicopters at the end of each day. The vertical bars display the mean percent coverage per day of the NAI with the values located on the left vertical axis. The line graph displays the mean number of helicopters that are still alive at the end of each day with the values located on the right vertical axis. The error bars are set at plus and minus one standard error to indicate the variability of the simulation results.

The results support what would be expected. As the vulnerability increases, the ability of the helicopters to maintain coverage decreases, along with the mean number of helicopters alive at the end of each day. With the low vulnerability rate, the helicopters are nearly able to maintain mean coverage of the NAI above 50% for almost two weeks.

With the medium vulnerability rate, the helicopters are no longer able to maintain mean coverage of the NAI above 50% after eleven days. With the high vulnerability rate, the helicopters can only maintain mean coverage of the NAI above 50% for 7 days. This emphasizes the fact that sufficient helicopters are necessary to sustain a prolonged operation, *unless* the Red threat is suppressed. It also informs T&E decision-makers that vulnerability of the helicopters is an important issue that dramatically affects the MOEs and needs to be carefully and thoroughly considered during operational field-testing.

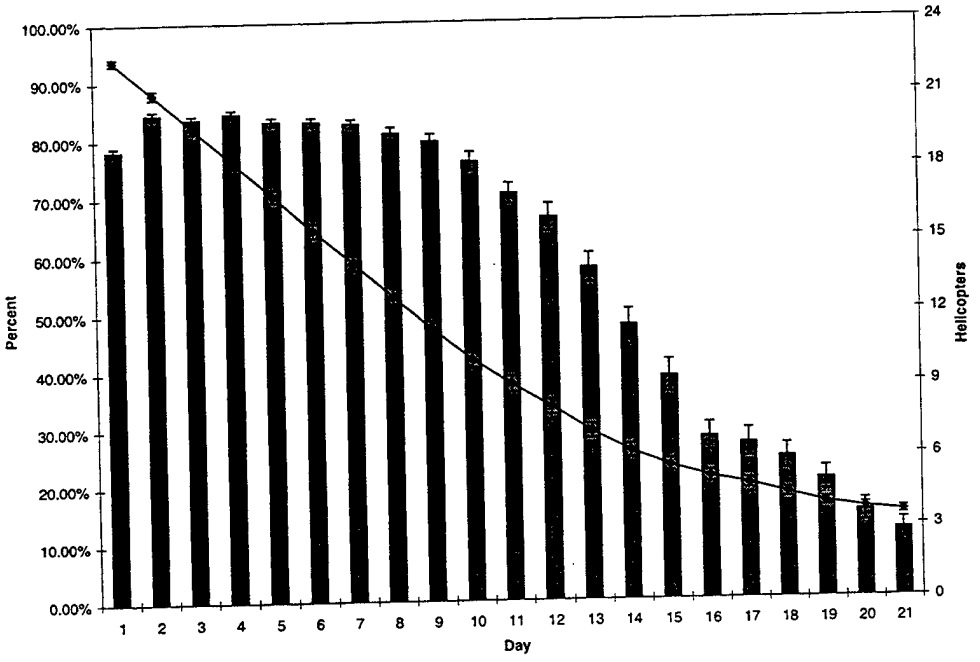

Figure 26. MOEs with Low Vulnerability for Model with a Non-homogeneous Failure Rate Process. Case I from Table 9 showing the effects of a low vulnerability rate on the mean percent of coverage and mean number of surviving helicopters. This graph can be compared to the iid times between failures in Figure 6.

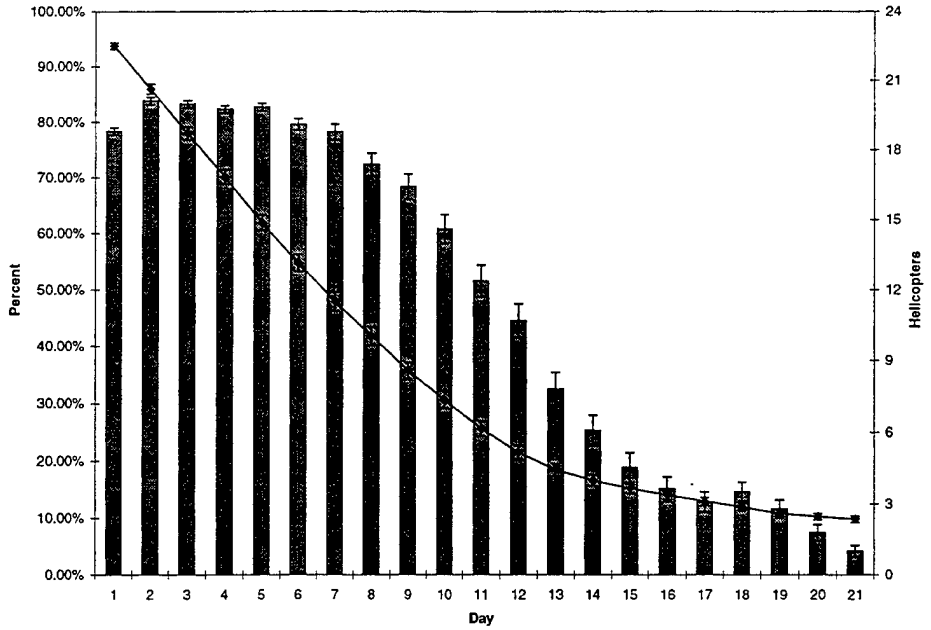

Figure 27. MOEs with Medium Vulnerability for Model with a Non-homogenous Failure Rate Process. Case II from Table 9 showing the effects of a medium vulnerability rate on the mean percent coverage and the mean number of helicopters surviving. This graph can be compared to the iid times between failures in Figure 7.

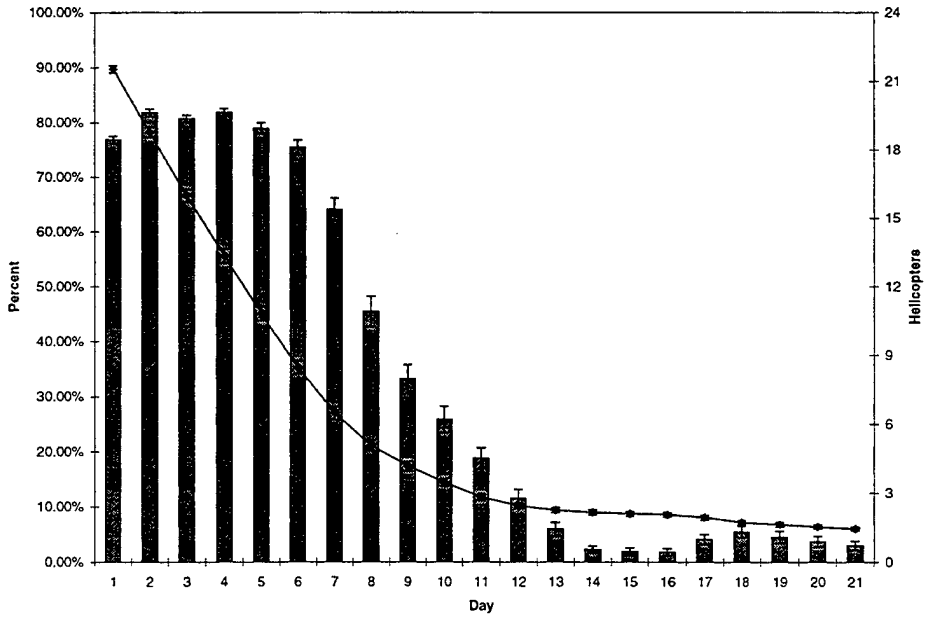

Figure 28. MOEs with High Vulnerability for Model with a Non-homogeneous Failure Rate Process. Case III from Table 9 showing the effects of a high vulnerability rate on the mean percent coverage and the mean number of helicopters surviving. This graph can be compared to the iid times between failures in Figure 8.

As the vulnerability increases, the rate of decrease in the number of helicopters surviving increases as time progresses since fewer helicopters are available to perform the mission. This causes the remaining helicopters to have to fly more hours and thus reach their scheduled maintenance flight hour limit sooner than normal. The helicopters are then temporarily no longer flying, but rather waiting in the scheduled maintenance queue for scheduled maintenance unless that scheduled maintenance duration is deliberately shortened or eliminated. In that case, the increasing occurrence of random failures will rapidly degrade coverage of the NAI.

B. SENSITIVITY ANALYSIS FOR TIME BETWEEN SCHEDULED MAINTENANCE ACTIONS

The time between scheduled maintenance actions is the number of flight hours, T_S, which a helicopter accumulates before being overhauled. This section examines the effect that different maintenance policies have on the MOEs. The cases chosen for comparison are shown below in Table 10.

	Time between Scheduled Maintenance Actions
Case I	300 Hours
Case II	400 Hours
Case III	500 Hours

Table 10. Description of Different Maintenance Policies for Model with a Non-homogeneous Failure Rate Process.

The other inputs, which remain constant, are as follows:

Numerical Illustration

⇒	24	Number of Helicopters
⇒	160	Speed of Helicopters (knots)
⇒	40	High-Threat Vulnerability (Mean Time until a Helicopter is Shot Down in Region) (hours)
⇒	80	Low-Threat Vulnerability (Mean Time until a Helicopter is Shot Down in Region) (hours)
⇒	1	Repair Facilities
⇒	1	Scheduled Maintenance Facilities
⇒	1	Mean Time to Repair a Failure (hours-Exponentially Distributed)
⇒	0.25	Mean Time of Helicopter Turnaround (hours-Exponentially Distributed)
⇒	144-192	Minimum/Maximum Time to Complete Scheduled Maintenance (hours-Uniformly Distributed)
⇒	0.1	λ_1 (Average Time between Mission-Affecting Failures = 8.5 hours)
⇒	5.8824e-5	λ_2 (Average Time between Mission-Affecting Failures = 8.5 hours)
⇒	0.1	Probability of a failure being fatal (Crash)

One hundred runs of the simulation were conducted for a two-week campaign to observe the effects of the different maintenance policies on the MOEs. Figure 29, Figure 30, and Figure 31 show the results of the varying maintenance policies. As the time between scheduled maintenance actions increases, the first four or five days of mean coverage do not change much between the different maintenance policies. As time progresses, the mean coverage over the NAI improves as the time between scheduled maintenance actions increases. The mean coverage does not drop off as rapidly in the beginning of the second week for the longer maintenance policies. By the end of the second week mean coverage does not change when taking into account the variability of the simulation as shown on the graphs by the error bars. Even though an improvement is shown in the mean coverage provided during the second week, more helicopters are being lost because of fatal mission-affecting failures and being shot down while attempting to provide this extra coverage. The average number of helicopters that finished the second

week alive decreased from 2.2 with the 300-hour maintenance policy to 1.6 with the 500-hour maintenance policy. As attrition and fatal mission-affecting failures kill more helicopters, the remaining helicopters must fly more missions. If the maintenance policy uses a shorter time period between scheduled maintenance actions, the helicopters reach their flight hour limit sooner and finish up the two-week period sitting on the ground waiting for scheduled maintenance. If the maintenance policy uses a longer time period between scheduled maintenance, the helicopters do not reach their flight hour limit as soon, more helicopters continue flying and are susceptible to being shot down and having fatal mission-affecting failures. In the model as currently formulated, the vulnerability of the helicopters does not decrease as the helicopter numbers decrease. Of course in practice, the Red force may diminish its defense when it observes a great decrease in helicopter reconnaissance. Perhaps a policy that "manages" the overhaul so that helicopters are sometimes overhauled before they need it would be appropriate.

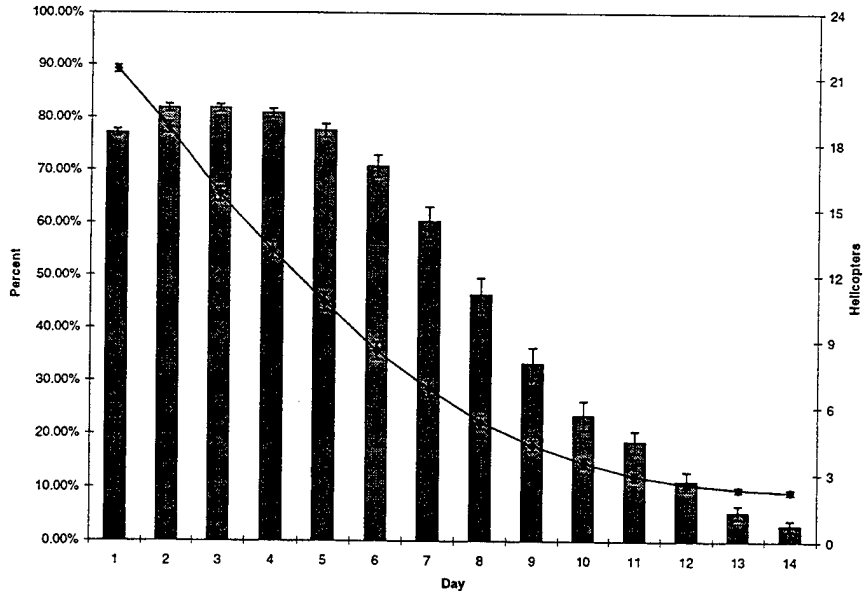

Figure 29. MOEs with 300-Hour Maintenance Policy for Model with a Non-homogeneous Failure Rate Process. Case I from Table 10 that shows the effects of 300 hours between scheduled maintenance activities on the mean percent coverage and the mean number of helicopters surviving. This graph can be compared to the iid times between failures in Figure 9.

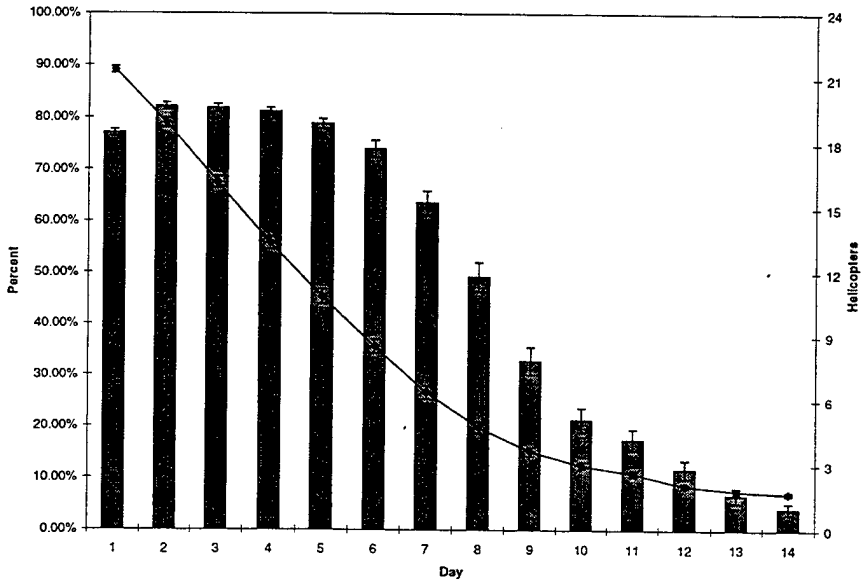

Figure 30. MOEs with 400-Hour Maintenance Policy for Model with a Non-homogeneous Failure Rate Process. Case II from Table 10 that shows the effects of 400 hours between scheduled maintenance activities on the mean percent coverage and the mean number of helicopters surviving. This graph can be compared to the iid times between failures in Figure 10.

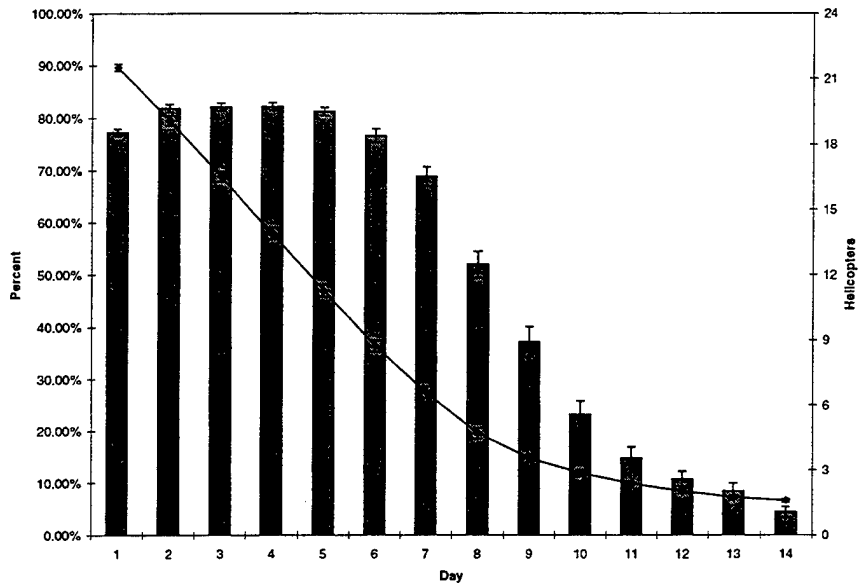

Figure 31. MOEs with 500-Hour Maintenance Policy for Model with a Non-Homogeneous Failure Rate Process. Case III from Table 10 that shows the effects of 500 hours between scheduled maintenance activities on the mean percent coverage and the mean number of surviving helicopters. This graph can be compared to the iid times between failures in Figure 11.

C. SENSITIVITY ANALYSIS FOR FAILURE-RATE AGING

The intensity function of the non-homogeneous Poisson process is determined by the numerical values assigned to λ_1 and λ_2 in Equation V-1. The intensity function of the process refers to the rapidity at which the expected number of failures per unit time changes from the initial time until the final time. In this case, the initial time is $T_0 = 0.0$, respectively the final time is $T_S = 300.0$ hours. These times correspond to a brand-new helicopter with an instantaneous failure rate equal to λ_1, and a helicopter just entering scheduled maintenance with an instantaneous failure rate equal to $\lambda_1+2\lambda_2 T_S$, respectively. The value for λ_1 is the initial failure rate for the helicopter, while the value for λ_2 represents the effect of aging on the helicopter's failure rate. Therefore, the lower the initial rate, the faster the rate function will have to increase (the larger λ_2 must be) to

result in a ATBMAF of 8.5 hours, as used in this analysis. Note that λ_2 is the "age effect;" the larger the value of λ_2, the greater the aging effect. Other functions can be used to induce sharper age dependence (Crowder, 1991).

This section examines the effect that different intensity functions, with the same calculated ATBMAF, have on the MOEs. The cases chosen for comparison are shown below in Table 11.

	λ_1	λ_2
Case I	0	3.92157×10^{-4}
Case II	0.1	5.8824×10^{-5}
Case III	0.117647	1.96078×10^{-10}

Table 11. Description of Aging Process for Model with a Non-homogeneous Failure Rate Process.

Note that Case I illustrates a maximum aging effect, Case II an intermediate aging effect, and Case III a minimum aging effect (comparable to iid Weibull with shape parameter one, i.e., exponential).

The other inputs, which remain constant, are as follows:

Numerical Illustration

⇒	24	Number of Helicopters
⇒	160	Speed of Helicopters (knots)
⇒	300	Mean Time between Scheduled Maintenance Actions (flight hours)
⇒	40	High-Threat Vulnerability (Mean Time until a Helicopter is Shot Down in Region) (hours)
⇒	80	Low-Threat Vulnerability (Mean Time until a Helicopter is Shot Down in Region) (hours)
⇒	1	Repair Facilities
⇒	1	Scheduled Maintenance Facilities
⇒	1	Mean Time to Repair a Failure (hours-Exponentially Distributed)
⇒	0.25	Mean Time of Helicopter Turnaround (hours-Exponentially Distributed)
⇒	144-192	Minimum/Maximum Time to Complete Scheduled Maintenance (hours-Uniformly Distributed)
⇒	0.1	Probability of a failure being fatal (Crash)

One hundred runs of the simulation were conducted for a two-week campaign to observe the effects of the differing Poisson process intensity functions on the MOEs. Figure 32, Figure 33, and Figure 34 show the results for the different intensity functions. The effects of the different aging models can be seen in how soon the mean percent coverage of the NAI begins to decline. Case I ($\lambda_1 = 0$) begins to reduce mean coverage after six days while for Case II and Case III mean coverage reduction begins after 4 or 5 days. There is also a negligible difference in the number of helicopters surviving at the end of each day. This is a result of little change in the mean number of failures experienced per campaign for each case examined. The values for the mean number of failures per campaign are 78.28, 78.07, and 80.52 for Case I, Case II, and Case III respectively. This corresponds to losing an average of 8 helicopters (10% of the mission-affecting failures) due to fatal mission-affecting failures. The mean number of helicopters shot down was about the same for each case as well. This results in

approximately the same total attrition rate for the helicopters in each case. Therefore, some of the differences in mean percent coverage of the NAI can be attributed to the rate at which the failures occur due to the different aging processes. The model used for the aging process does not have a strong age effect as can be seen by the low values used for λ_2. Even with this low age effect, differences can be seen in the percent coverage of the NAI. If an aging model with a stronger age effect were used, even greater differences in the percent coverage would be expected. Hence, the rate of aging is a parameter that affects the MOEs and should be addressed.

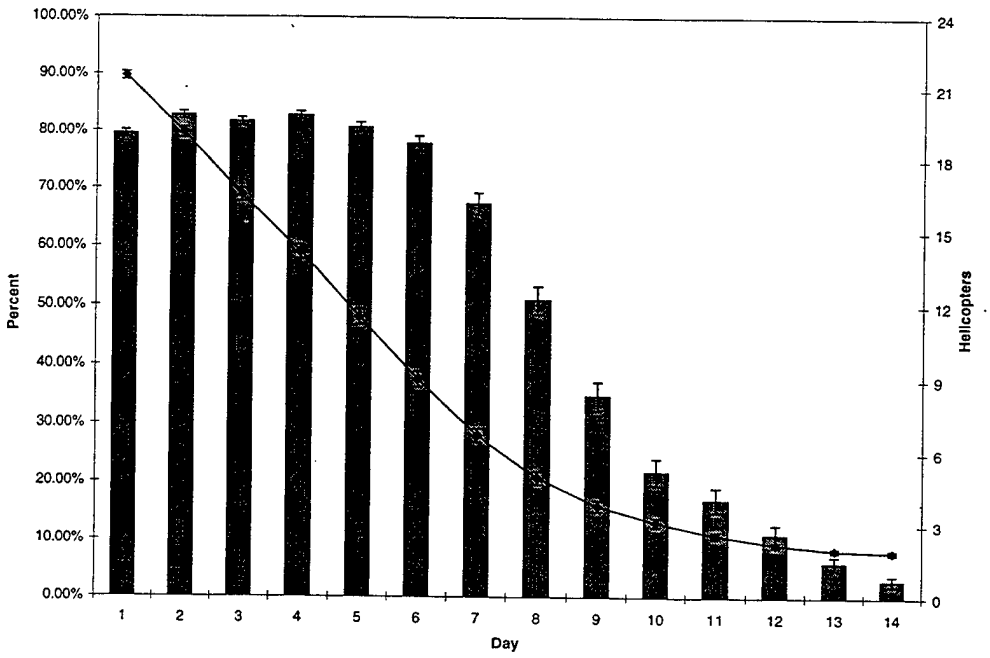

Figure 32. MOEs for Case I of the Varying Rate Functions. Case I from Table 11 that shows the effects of aging on the mean percent coverage and the mean number of helicopters surviving with an initial rate of failure set to zero and the mean number of failures over 300 flight hours equal to 300/8.5.

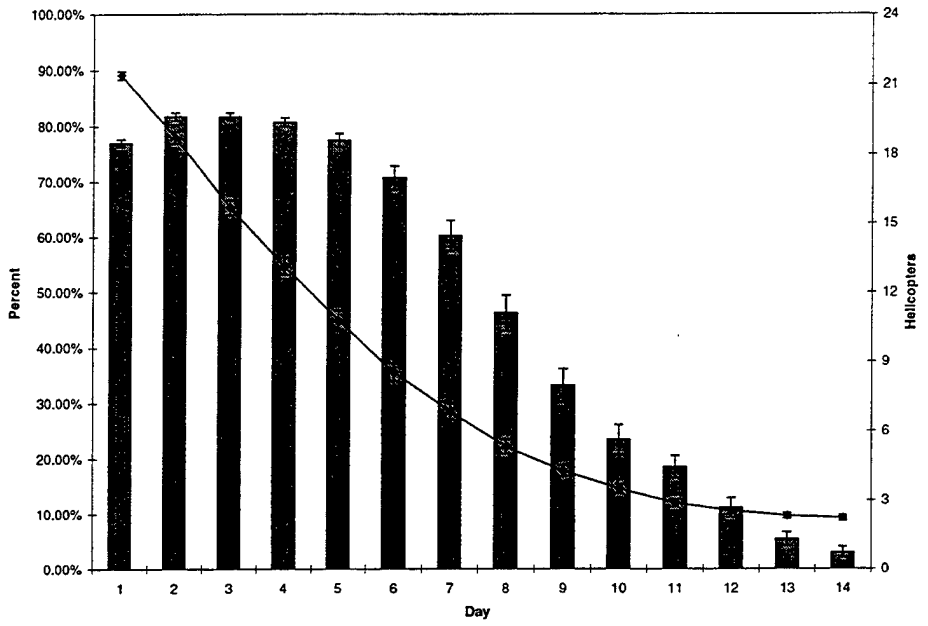

Figure 33. MOEs for Case II of the Varying Rate Functions. Case II from Table 11 that shows the effects of aging on the mean percent coverage and the mean number of helicopters surviving with an initial rate function set equal to 0.1 and the mean number of failures over 300 hours equal to 300/8.5.

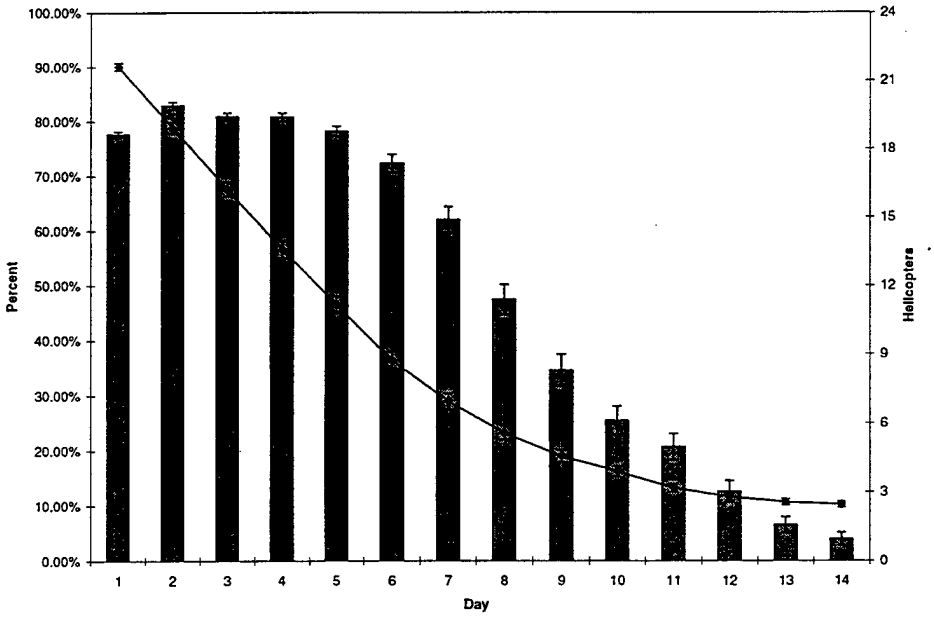

Figure 34. MOEs for Case III of the Varying Rate Functions. Case III from Table 11 that shows the effects of aging on the mean percent coverage and the mean number of helicopters surviving with a negligible aging effect, an initial failure rate set equal to 0.117647 and the mean number of failures over 300 hours equal to 300/8.5.

D. SENSITIVITY ANALYSIS FOR AVERAGE TIME BETWEEN MISSION-AFFECTING FAILURES

This section examines the effect that different average times between mission-affecting failures have on the MOEs. The cases chosen for observation are shown below in Table 12.

	λ_1	λ_2	Average Time between Mission-Affecting Failures: $\left(\frac{300}{\lambda_1(300)+\lambda_2(300)^2}\right)$
Case I	0.01	7.50980×10^{-4}	4.25 Hours
Case II	0.01	3.5824×10^{-4}	8.5 Hours
Case III	0.01	1.62745×10^{-4}	17.0 Hours

Table 12. Description of ATBMAF for Model with a Non-homogeneous Failure Rate Process.

The other inputs, which remain constant, are as follows:

Numerical Illustration

⇒	24	Number of Helicopters
⇒	160	Speed of Helicopters (knots)
⇒	300	Time between Scheduled Maintenance Actions (flight hours)
⇒	40	High-Threat Vulnerability (Mean Time until a Helicopter is Shot Down in Region) (hours)
⇒	80	Low-Threat Vulnerability (Mean Time until a Helicopter is Shot Down in Region) (hours)
⇒	1	Repair Facilities
⇒	1	Scheduled Maintenance Facilities
⇒	1	Mean Time to Repair a Failure (hours-Exponentially Distributed)
⇒	0.25	Mean Time of Helicopter Turnaround (hours-Exponentially Distributed)
⇒	144-192	Minimum/Maximum Time to Complete Scheduled Maintenance (hours-Uniformly Distributed)
⇒	0.1	Probability of a failure being fatal (Crash)

One hundred runs of the simulation were conducted for a two-week campaign to observe the effects of the different ATBMAF on the MOEs. Figure 35, Figure 36, and

Figure 37 show the results for each of the different ATBMAF. The average time between mission-affecting failures has a dramatic effect on both the mean percent coverage of the NAI per day and the mean number of helicopters surviving at the end of each day. As the ATBMAF increases, on the average fewer failures are experienced during the campaign, which results in several areas of performance of the system improving. With fewer failures, more helicopters are able to successfully complete an entire mission without having to return to home base for repairs. This results in more and longer times on station for each helicopter pair, thus improving the mean percent coverage of the Named Area of Interest. The diminished mean number of failures also results in less time being spent in the repair facility and more helicopters being available to perform the assigned mission. Also as fewer failures are experienced, fewer crashes (modeled as 10% of the number of MAF) occur. This results in a lower total attrition rate for the helicopters during the campaign. Thus, the ATBMAF needs to be well monitored during actual field-testing. It may well increase as failure modes are discovered and rectified. Response of this parameter to environmental influences must also be tested and monitored.

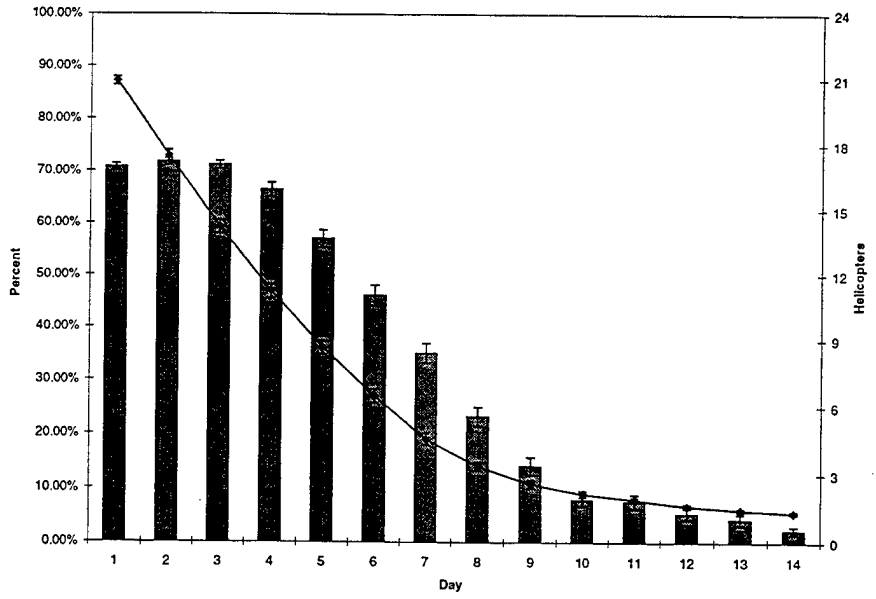

Figure 35. MOEs with ATBMAF equal to 4.25 Hours for Model with a Non-homogeneous Failure Rate Process. Case I from Table 12 that shows the effects with an ATBMAF equal to 4.25 hours on the mean percent coverage and the mean number of helicopters surviving. This graph can be compared to the iid times between failures in Figure 12.

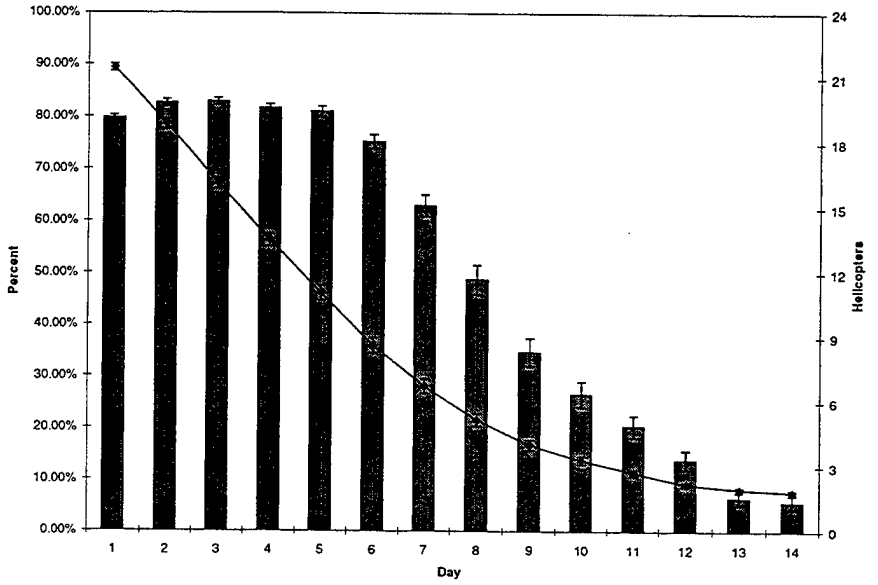

Figure 36. MOEs with ATBMAF equal to 8.5 hours for Model with a Non-homogeneous Failure Rate Process. Case II from Table 12 that shows the effects with an ATBMAF equal to 8.5 hours on the mean percent coverage and the mean number of helicopters surviving. This graph can be compared to the iid times between failures in Figure 13.

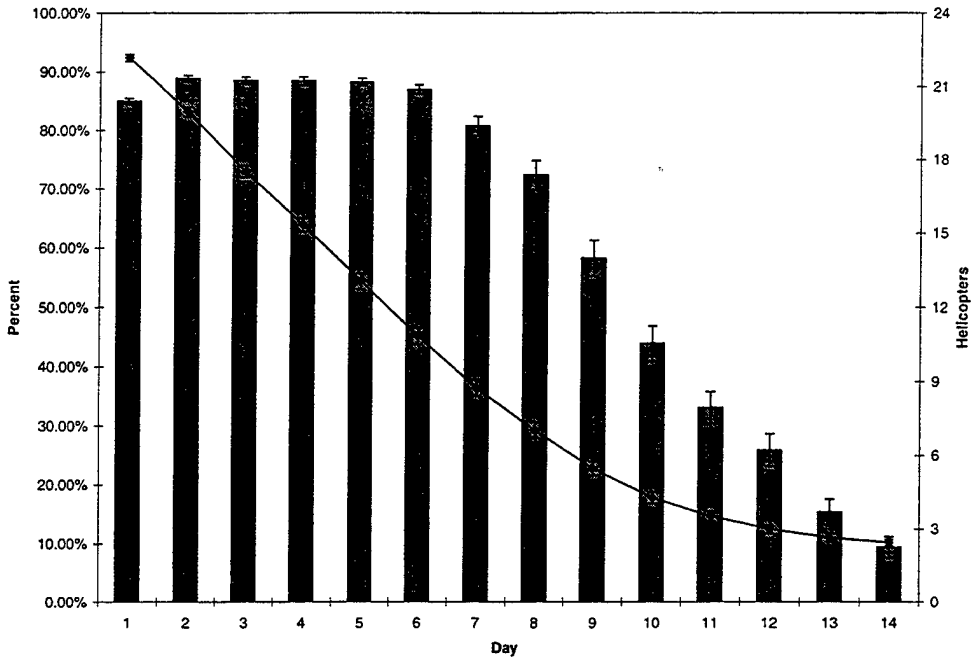

Figure 37. MOEs with ATBMAF equal to 17.0 Hours for Model with a Non-homogeneous Failure Rate Process. Case III from Table 12 that shows the effects with an ATBMAF equal to 17.0 hours on the mean percent coverage and the mean number of helicopters remaining. This graph can be compared to the iid times between failures in Figure 14.

E. SENSITIVITY ANALYSIS OF OVERHAUL TIMES

The overhaul time is that amount of time needed to complete scheduled maintenance on a helicopter and return it to service. It is being modeled with a uniform distribution specified by the minimum and maximum times to complete the scheduled maintenance. This section examines the effects of different overhaul times on the MOEs. The cases chosen for comparison are listed below in Table 13.

	Minimum Overhaul Time	Maximum Overhaul Time
Case I	48 Hours	96 Hours
Case II	96 Hours	144 Hours
Case III	144 Hours	192 Hours

Table 13. Description of Overhaul Times for Model with a Non-homogeneous Failure Rate Process.

The other inputs, which remain constant, are as follows:

Numerical Illustration

⇒	24	Number of Helicopters
⇒	160	Speed of Helicopters (knots)
⇒	300	Time between Scheduled Maintenance Actions (flight hours)
⇒	40	High-Threat Vulnerability (Mean Time until a Helicopter is Shot Down in Region) (hours)
⇒	80	Low-Threat Vulnerability (Mean Time until a Helicopter is Shot Down in Region) (hours)
⇒	1	Repair Facilities
⇒	1	Scheduled Maintenance Facilities
⇒	1	Mean Time to Repair a Failure (hours-Exponentially Distributed)
⇒	0.25	Mean Time of Helicopter Turnaround (hours-Exponentially Distributed)
⇒	0.1	λ_1 (Mean Time between Mission-Affecting Failures = 8.5 hours)
⇒	5.8824e-5	λ_2 (Mean Time between Mission-Affecting Failures = 8.5 hours)
⇒	0.1	Probability of a failure being fatal (Crash)

One hundred runs of the simulation were conducted for a two-week campaign to observe the effects of the different overhaul times on the MOEs. In each case, one scheduled maintenance facility was available for overhaul. Figure 38, Figure 39, and Figure 40 show the results for the different overhaul times. The effect of the different overhaul times begins to show up after four days. The longer overhaul times result in fewer helicopters being available once they reach their flight hour limit since they are now sitting on the ground waiting for the maintenance facility to begin the overhaul. This results in fewer helicopters flying the assigned mission, and thus less mean coverage of the NAI being provided. The longer overhaul times do result in more helicopters surviving at the end of the campaign. This is once again the result of helicopters being backed up in the maintenance facility, which results in fewer helicopters flying missions, and thus fewer helicopter crashes and lower attrition due to enemy action.

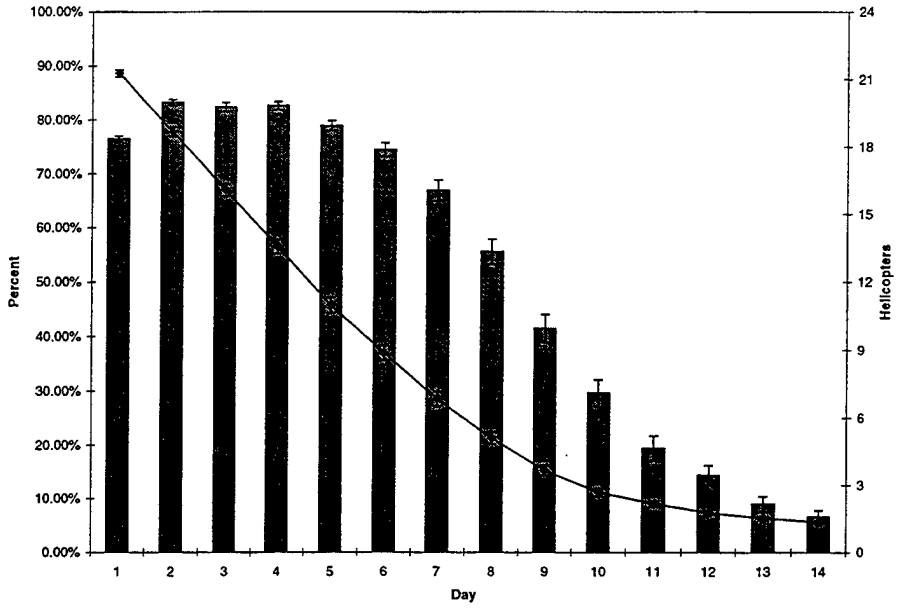

Figure 38. MOEs with Short Overhaul Times for Model with a Non-homogeneous Failure Rate Process. Case I from Table 13 that shows the effects of a short overhaul time on the mean percent coverage and the mean number of helicopters surviving. This graph can be compared to iid times between failures in Figure 15.

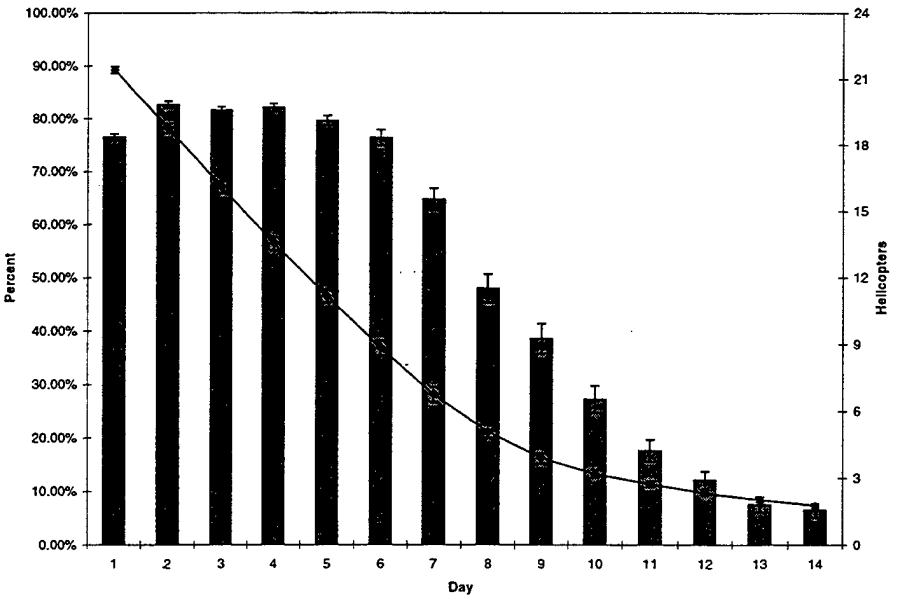

Figure 39. MOEs with Medium Overhaul Times for Model with a Non-homogeneous Failure Rate Process. Case II from Table 13 that shows the effects of a medium overhaul time on the mean percent coverage and the mean number of helicopters surviving. This graph can be compared to iid times between failures in Figure 16.

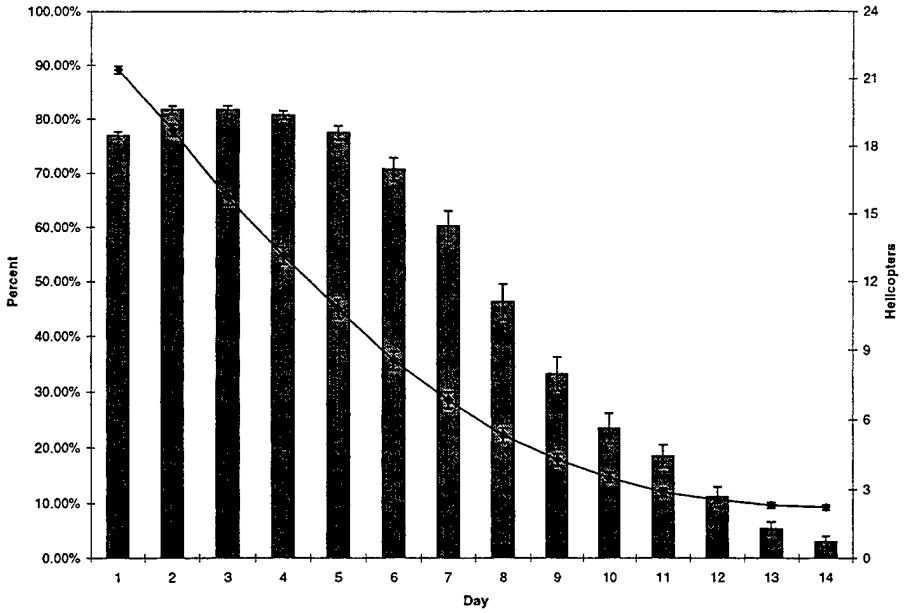

Figure 40. MOEs with Long Overhaul Times for Model with a Non-homogeneous Failure Rate Process. Case III from Table 13 that shows the effects of a long overhaul time on the mean percent coverage and the mean number of helicopters surviving. This graph can be compared to iid times between failures in Figure 17.

F. SENSITIVITY ANALYSIS OF THE EFFECT OF CHANGING NUMBERS OF SCHEDULED MAINTENANCE FACILITIES

This section examines the effect that different numbers of scheduled maintenance facilities have on the MOEs. A scheduled maintenance facility is one for which the maintenance manager directs helicopters that require overhaul. The helicopters are initially setup such that their entrance into the maintenance facility is periodically staggered. The cases chosen for comparison are shown below in Table 14.

	Number of Scheduled Maintenance Facilities
Case I	1
Case II	2
Case III	4

Table 14. Description of the Number of Scheduled Maintenance Facilities for Model with a Non-homogeneous Failure Rate Process.

The other inputs, which remain constant, are as follows:

Numerical Illustration

⇒	24	Number of Helicopters
⇒	160	Speed of Helicopters (knots)
⇒	300	Time between Scheduled Maintenance Actions (flight hours)
⇒	40	High-Threat Vulnerability (Mean Time until a Helicopter is Shot Down in Region) (hours)
⇒	80	Low-Threat Vulnerability (Mean Time until a Helicopter is Shot Down in Region) (hours)
⇒	1	Repair Facilities
⇒	1	Mean Time to Repair a Failure (hours-Exponentially Distributed)
⇒	0.25	Mean Time of Helicopter Turnaround (hours-Exponentially Distributed)
⇒	0.1	λ_1 (Mean Time between Mission-Affecting Failures = 8.5 hours)
⇒	5.8824e-5	λ_2 (Mean Time between Mission-Affecting Failures = 8.5 hours)
⇒	144-192	Minimum/Maximum Time to Complete Scheduled Maintenance (hours-Uniformly Distributed)
⇒	0.1	Probability of a failure being fatal (Crash)

One hundred runs of the simulation were conducted for a two-week campaign to observe the effects of the different numbers of scheduled maintenance facilities on the MOEs. Figure 41, Figure 42, and Figure 43 show the results for each of the different numbers. The results show that as the number of scheduled maintenance facilities increases, the helicopters are able to maintain a higher percentage of coverage later in the campaign. In the short term, the number of maintenance facilities has very little effect. As time progresses and more helicopters are sent in for overhaul, the number of scheduled maintenance facilities has a large impact. On the last day of the campaign, mean coverage more than doubled from 3% with one scheduled maintenance facility to over 7% percent for just one additional facility and to nearly 10% with an additional three facilities. This does take a toll on the number of helicopters remaining at the end of the campaign since fewer helicopters are waiting in the maintenance facilities and more are

returned to conduct the assigned mission in a timely manner. These helicopters are once again subjected to attrition from enemy action and crashes.

If these effects are to be seen during actual testing, the tests will need to be of long enough duration, and tests should not be conducted with helicopters that have all just completed an overhaul. The helicopters should be similar to those that would be used in the field, which have staggered flight hours to facilitate staggered overhauls.

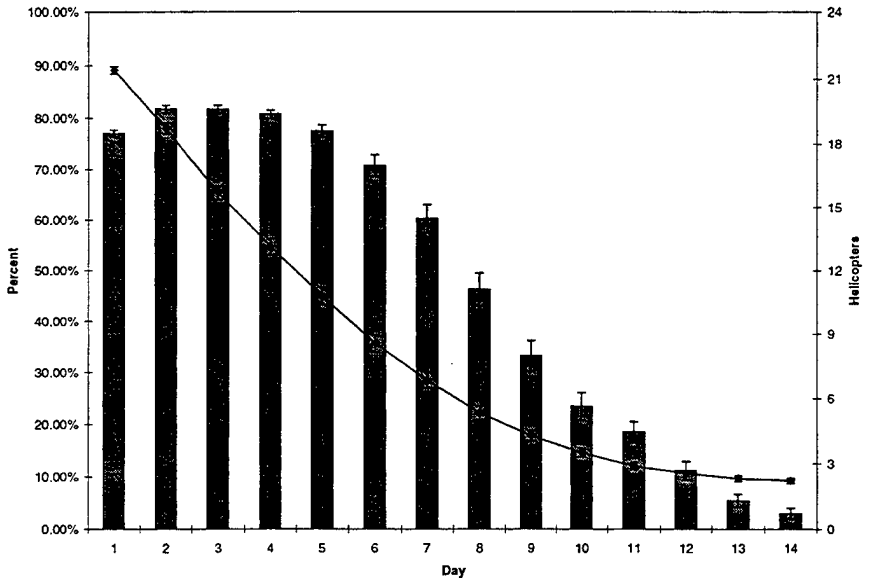

Figure 41. MOEs with One Scheduled Maintenance Facility for Model with a Non-homogeneous Failure Rate Process. Case I from Table 14 that shows the effects of one scheduled maintenance facility on the mean percent coverage and the mean number of helicopters surviving. This graph can be compared to the iid times between failures in Figure 18.

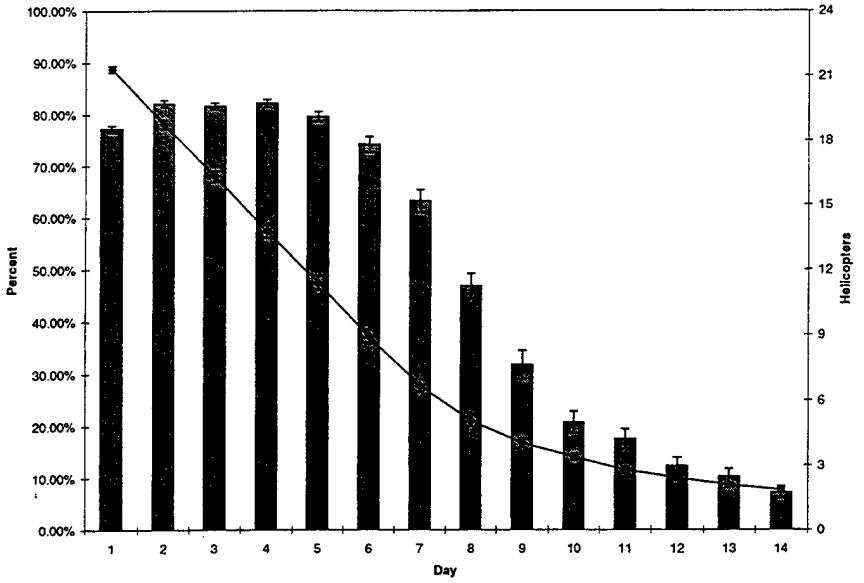

Figure 42. MOEs with Two Scheduled Maintenance Facilities for Model with a Non-homogeneous Failure Rate Process. Case II from Table 14 that shows the effects of two scheduled maintenance facilities on the mean percent coverage and the mean number of helicopters surviving. This graph can be compared to the iid times between failures in Figure 19.

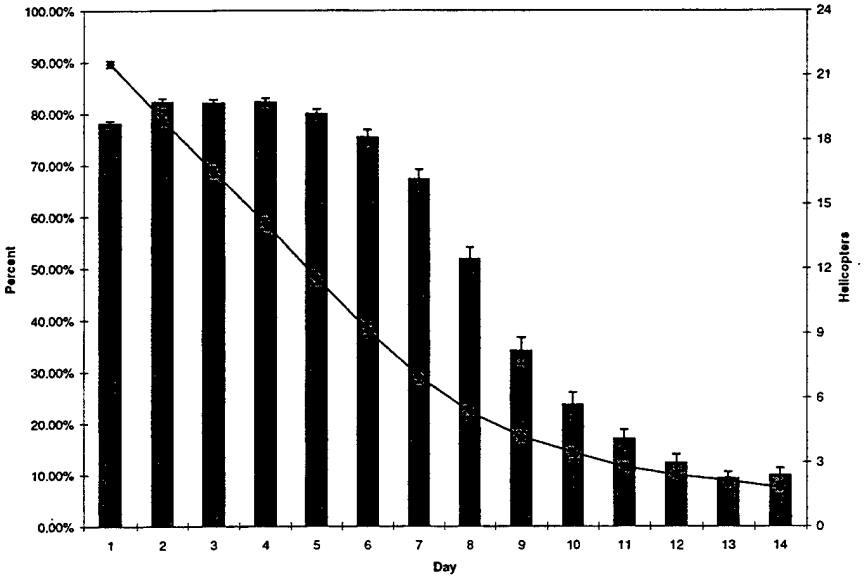

Figure 43. MOEs with Four Scheduled Maintenance Facilities for Model with a Non-homogeneous Failure Rate Process. Case III from Table 14 that shows the effects of four scheduled maintenance facilities on the mean percent coverage and the mean number of helicopters surviving. This graph can be compared to iid times between failures in Figure 20.

G. SENSITIVITY ANALYSIS FOR THE NUMBER OF REPAIR FACILITIES

This section examines the effect that different numbers of repair facilities have on the MOEs. A repair facility is one in which the maintenance manager directs helicopters that have experienced a MAF and need to be repaired. The repair facility also conducts helicopter turnaround tasks (rearming and refueling). The repair facilities in this analysis operate using a priority maintenance policy that selects the helicopter in the repair facility with the shortest repair/turnaround time to be serviced first. The cases chosen for observation are shown below in Table 15.

	Number of Repair Facilities
Case I	1
Case II	2
Case III	4

Table 15. Description of the Number of Repair Facilities for Model with a Non-homogeneous Failure Rate Process.

The other inputs, which remain constant, are as follows:

Numerical Illustration

⇒	24	Number of Helicopters
⇒	160	Speed of Helicopters (knots)
⇒	300	Time between Scheduled Maintenance Actions (flight hours)
⇒	40	High-Threat Vulnerability (Mean Time until a Helicopter is Shot Down in Region) (hours)
⇒	80	Low-Threat Vulnerability (Mean Time until a Helicopter is Shot Down in Region) (hours)
⇒	1	Scheduled Maintenance Facilities
⇒	1	Mean Time to Repair a Failure (hours-Exponentially Distributed)
⇒	0.25	Mean Time of Helicopter Turnaround (hours-Exponentially Distributed)
⇒	0.1	λ_1 (Mean Time between Mission-Affecting Failures = 8.5 hours)
⇒	5.8824e-5	λ_2 (Mean Time between Mission-Affecting Failures = 8.5 hours)
⇒	144-192	Minimum/Maximum Time to Complete Scheduled Maintenance (hours-Uniformly Distributed)
⇒	0.1	Probability of a failure being fatal (Crash)

One hundred runs of the simulation were conducted for a two-week campaign to observe the effects of the different numbers of repair facilities on the MOEs. Figure 44, Figure 45, and Figure 46 show the results for each of the different numbers of repair facilities. The results show that the number of repair facilities has little effect on either of the MOEs. This is because of a sufficient number of helicopters at the beginning of the campaign, and attrition of helicopters during the campaign. Even if the single repair facility case has a queue of helicopters, it is able to complete the repairs prior to the repair backlog causing a detrimental problem. The current repair rate is too high to be influential.

Once again, the reader is reminded that for the parameters chosen for these cases, the repair facilities were never challenged. For the 3 cases observed, the mean number of non-fatal mission-affecting failures experienced per campaign was 70.75. This means that on average there were approximately 5.05 MAF that needed to be repaired. Using the mean time to repair of 1.0 hours, the repair facility was busy repairing a mission-affecting failure on average just over 5 hours per day. The average time needed to rearm and refuel all 24 helicopters using a mean turnaround time of 0.25 hours is 6 hours. Even if all 24 helicopters need to be reamed and refueled on any given day, the average time that the repair facility is busy is just over 11 hours per day.

The cases analyzed are far from stretching the limits of one repair facility, let alone two or four. More analysis needs to be done in this area by looking at longer repair times or fewer helicopters. In such cases the reduction in force size due to one or two helicopters being in the repair facility may dramatically affect the MOEs.

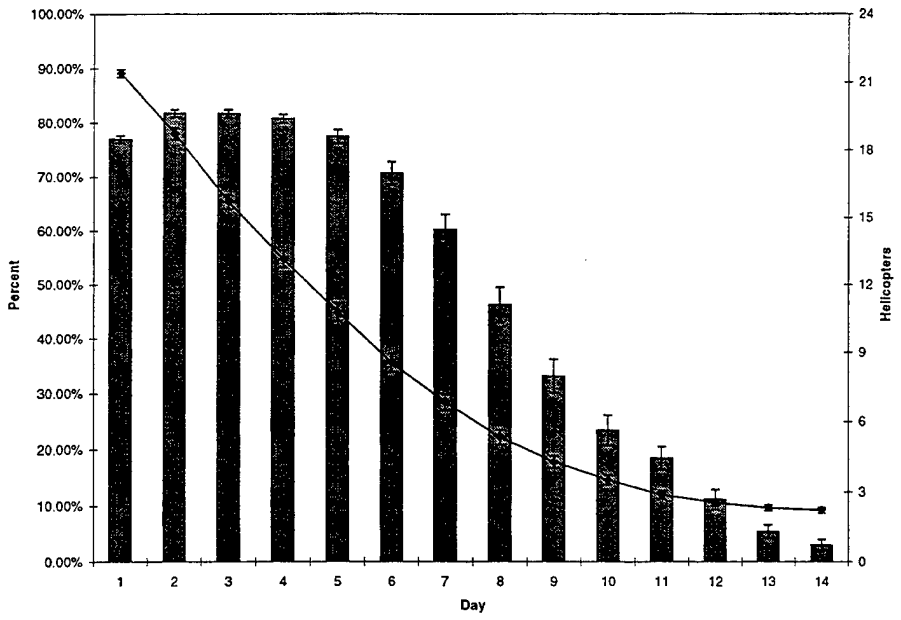

Figure 44. MOEs with a Single Repair Facility for Model with a Non-homogeneous Failure Rate Process. Case I from Table 15 that shows the effects of a single repair facility on the mean percent coverage and the mean number of helicopters surviving. This graph can be compared to iid times between failures in Figure 21.

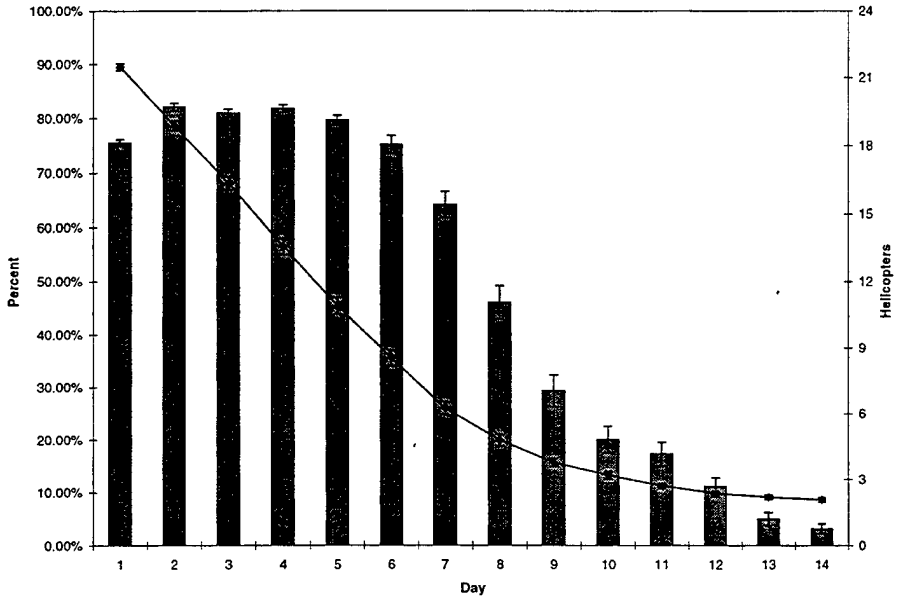

Figure 45. MOEs with Two Repair Facilities for Model with a Non-homogeneous Failure Rate Process. Case II from Table 15 that shows the effects of two repair facilities on the mean percent coverage and the mean number of helicopters surviving. This graph can be compared to iid times between failures in Figure 22.

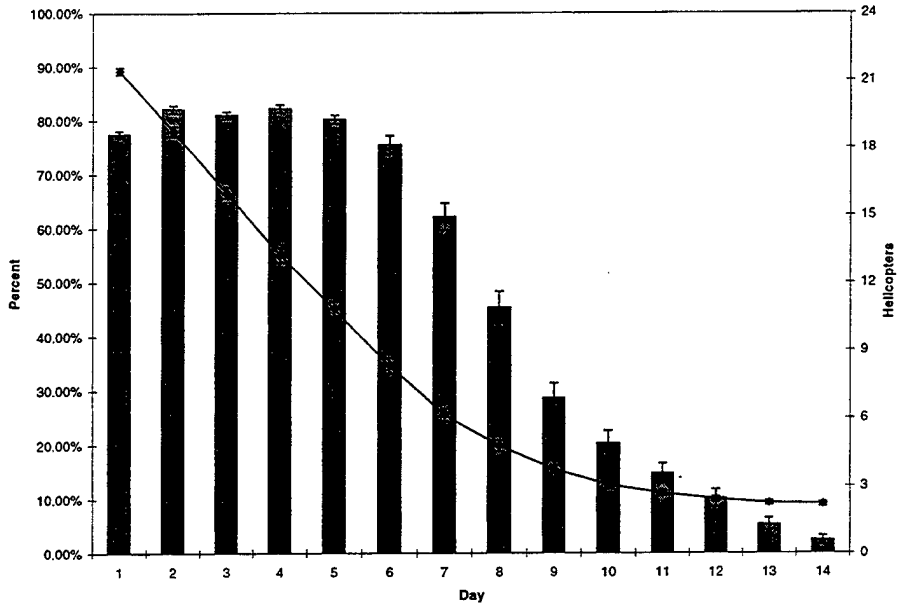

Figure 46. MOEs with Four Repair Facilities for Model with a Non-homogeneous Failure Rate Process. Case III from Table 15 that shows the effects of four repair facilities on the mean percent coverage and the mean number of helicopters surviving. This graph can be compared to iid times between failures in Figure 23.

H. SENSITIVITY ANALYSIS FOR PRIORITY MAINTENANCE

Priority maintenance is the maintenance policy of determining the helicopter in the repair queue with the shortest repair/turnaround time and conducting repairs or services on this helicopter first. If the priority maintenance policy is not in effect, the repair system operates on a first-come, first-served, basis. This section examines the effects of the two different maintenance policies on the MOEs. The cases chosen are shown below in Table 16.

	Priority Maintenance
Case I	TRUE
Case II	FALSE

Table 16. Description of Priority Maintenance Policies for Model with a Non-homogenous Failure Rate Process.

The other inputs, which remain constant, are as follows:

Numerical Illustration

⇒	24	Number of Helicopters
⇒	160	Speed of Helicopters (knots)
⇒	300	Time between Scheduled Maintenance Actions (flight hours)
⇒	40	High-Threat Vulnerability (Mean Time until a Helicopter is Shot Down in Region) (hours)
⇒	80	Low-Threat Vulnerability (Mean Time until a Helicopter is Shot Down in Region) (hours)
⇒	2	Scheduled Maintenance Facilities
⇒	2	Repair Facilities
⇒	1	Mean Time to Repair a Failure (hours-Exponentially Distributed)
⇒	0.25	Mean Time of Helicopter Turnaround (hours-Exponentially Distributed)
⇒	0.1	λ_1 (Mean Time between Mission-Affecting Failures = 8.5 hours)
⇒	5.8824e-5	λ_2 (Mean Time between Mission-Affecting Failures = 8.5 hours)
⇒	144-192	Minimum/Maximum Time to Complete Scheduled Maintenance (hours-Uniformly Distributed)
⇒	0.1	Probability of a failure being fatal (Crash)

One hundred runs of the simulation were conducted for a two-week campaign to observe the effects of the different maintenance policies on the MOEs. Figure 47 and Figure 48 show the results for each of the different policies. As expected from the previous section, there is very little difference between the results for the two different maintenance policies. The mean numbers of surviving helicopters are comparable throughout the campaign, as is the mean percent coverage per day of the NAI. There is essentially no difference between the two policies as far as the two observed MOEs are concerned since the repair facilities are not being challenged.

As previously discussed in Section G on page 80 the cases analyzed do not test the repair facilities at its limits. Here again the repair facility spends on average just over 5 hours per day performing repairs. In order to see the effects of priority maintenance, the repair facility must first be tested near its limits. This can be accomplished by increasing

the number of failures or by increasing the average amount of time necessary to complete a repair of a mission-affecting failure.

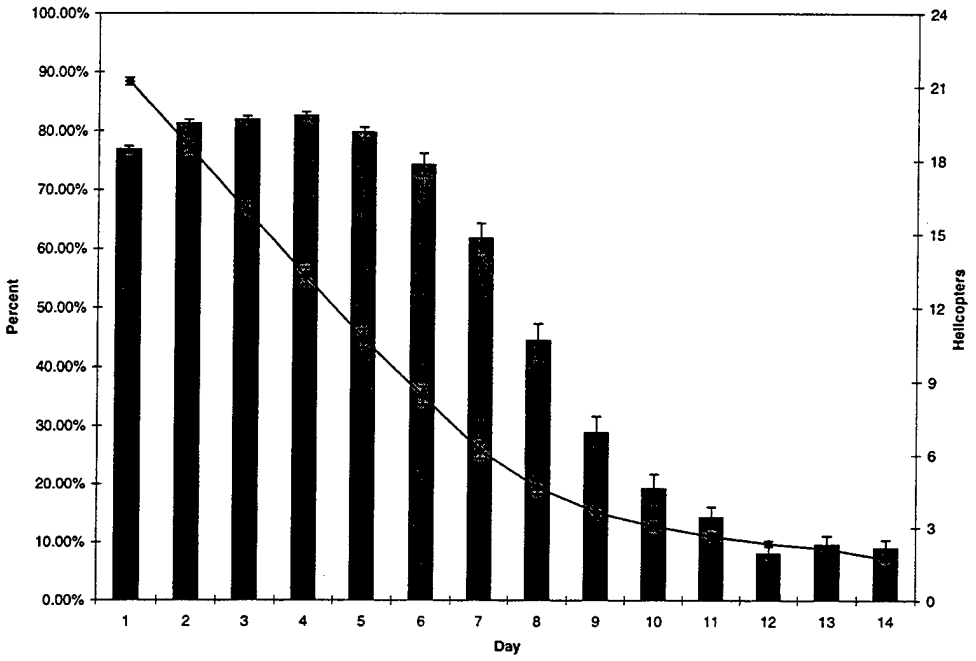

Figure 47. MOEs with Priority Maintenance for Model with a Non-homogeneous Failure Rate Process. Case I from Table 16 that shows the effects of priority maintenance on the mean percent coverage and the mean number of helicopters surviving. This graph can be compared to iid times between failures in Figure 24.

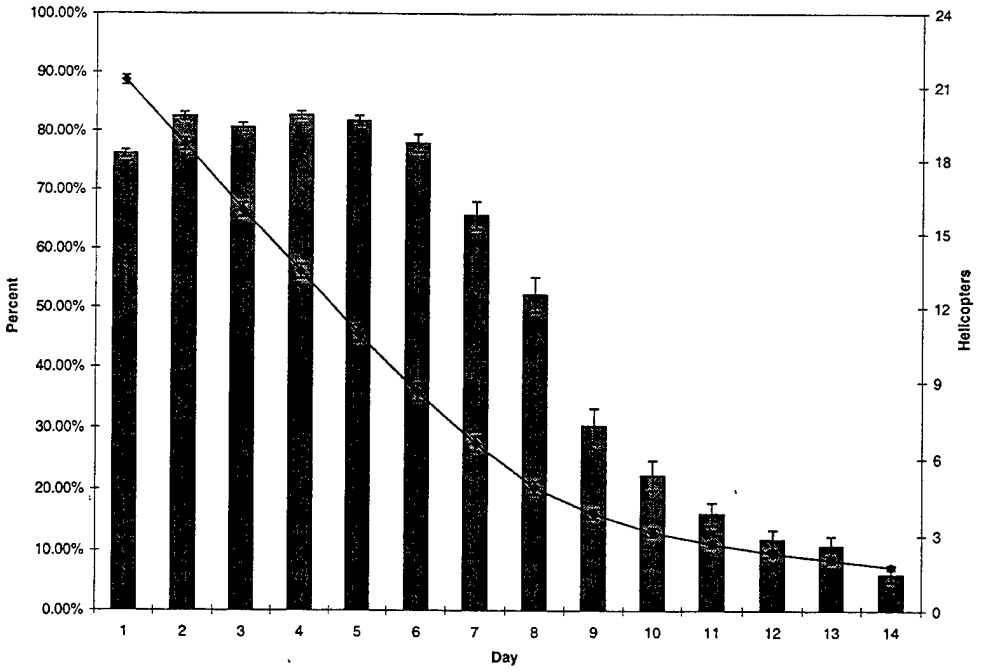

Figure 48. MOEs with First-Come, First-Served, Maintenance for Model with a Non-homogeneous Failure Rate Process. Case II from Table 16 that shows the effects of non-priority maintenance on the mean percent coverage and the mean number of helicopters surviving. This graph can be compared to iid times between failures in Figure 25.

I. SUMMARY ANALYSIS FOR THE NON-HOMOGENEOUS POISSON (INCREASING FAILURE RATE) FUNCTION

This chapter focused on the behavior of the MOEs with the underlying distribution for the mission-affecting failures as a non-homogeneous Poisson Process that represents the aging of equipment by decreasing the time between failures as age increases. This results in more failures per unit time as the equipment ages. The dominant sensitivities from the analysis were once again the vulnerability of the helicopters, and the mean time between mission-affecting failures. The aging effect, as modeled here, did not produce any drastic changes in the MOEs. This was expected since the aging effect ($\lambda 2$) is such a small number (on the order of 10^{-5}) for most cases. Other

aging models can have a more influential effect. The lesson for OT&E is to monitor time-between-failure data to detect the extent of an aging effect.

VI. ADDITIONAL COMPARISONS OF SIMULATIONS

The MOEs displayed in this chapter are the mean percent coverage per day of the NAI and the mean number of helicopter surviving at the end of each day. The 25^{th}, 50^{th}, and 75^{th} percentiles for each of the MOEs appear in Appendix D. Appendix D also displays for a campaign the mean number of MAF, mean number of fatal failures, and mean number of helicopters shot down. The mean repair and turnaround time, mean number of missions started, probability of returning to base safely, mean time spent in the high threat regions, mean survival time of individual helicopters, and the mean number of helicopters in the repair system for each campaign are also displayed in Appendix D.

A. COMARISON OF THE MODEL WITH IID TIMES BETWEEN FAILURES AND THE MODEL WITH A NON-HOMOGENEOUS POISSON FAILURE RATE

This section compares the model with independent identically distributed times between mission-affecting failures to a model with a non-homogeneous Poisson Failure Rate process. The cases chosen are shown in Table 17.

	Parameters
Model with iid Times between Failures	Shape = 1.0, Scale = 8.5
Model with Non-homogeneous Poisson Failures	$\lambda_1 = 0.1$, $\lambda_2 = 5.8824 \times 10^{-5}$

Table 17. Description of Models being Compared.

The other inputs, which remain constant, are as follows:

Numerical Illustration

⇒	24	Number of Helicopters
⇒	160	Speed of Helicopters (knots)
⇒	300	Time between Scheduled Maintenance Actions (flight hours)
⇒	40	High-Threat Vulnerability (Mean Time until a Helicopter is Shot Down in Region) (hours)
⇒	80	Low-Threat Vulnerability (Mean Time until a Helicopter is Shot Down in Region) (hours)
⇒	1	Scheduled Maintenance Facilities
⇒	1	Mean Time to Repair a Failure (hours-Exponentially Distributed)
⇒	0.25	Mean Time of Helicopter Turnaround (hours-Exponentially Distributed)
⇒	8.5	Mean Time between Mission-Affecting Failures (hours)
⇒	144-192	Minimum/Maximum Time to Complete Scheduled Maintenance (hours-Uniformly Distributed)
⇒	0.1	Probability of a failure being fatal (Crash)

One hundred runs of the simulation were conducted for a two-week campaign to observe compare the effects of the two separate models. Figure 49 and Figure 50 show the results of the simulations for comparison. There is not much difference between the output for the two models. This is an expected result since the aging effects are not very strong in the non-homogeneous Poisson failure time model. As the strength of the aging effect decreases (λ_2 approaches zero), the non-homogeneous Poisson failure time model approaches the model with iid times between failure, here an exponential distribution. The Wiebull distribution with a shape parameter of one is also an exponential distribution. This explains why there is very little difference between the two models shown.

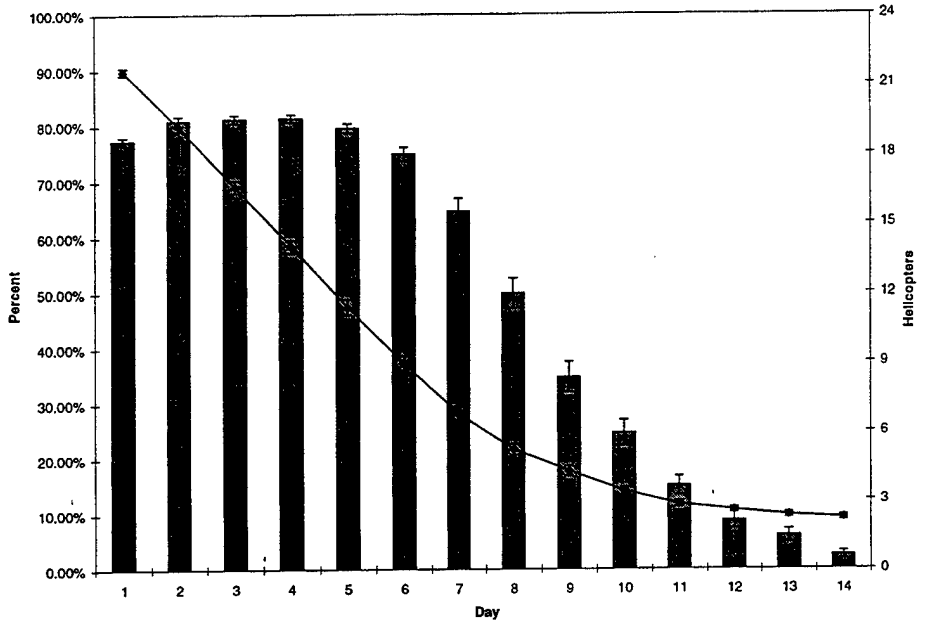

Figure 49. MOEs for the Model with iid Times between Mission-Affecting Failures. This graph shows the effects on the results of the simulation for the model using a Weibull distribution to generate times between mission-affecting failures.

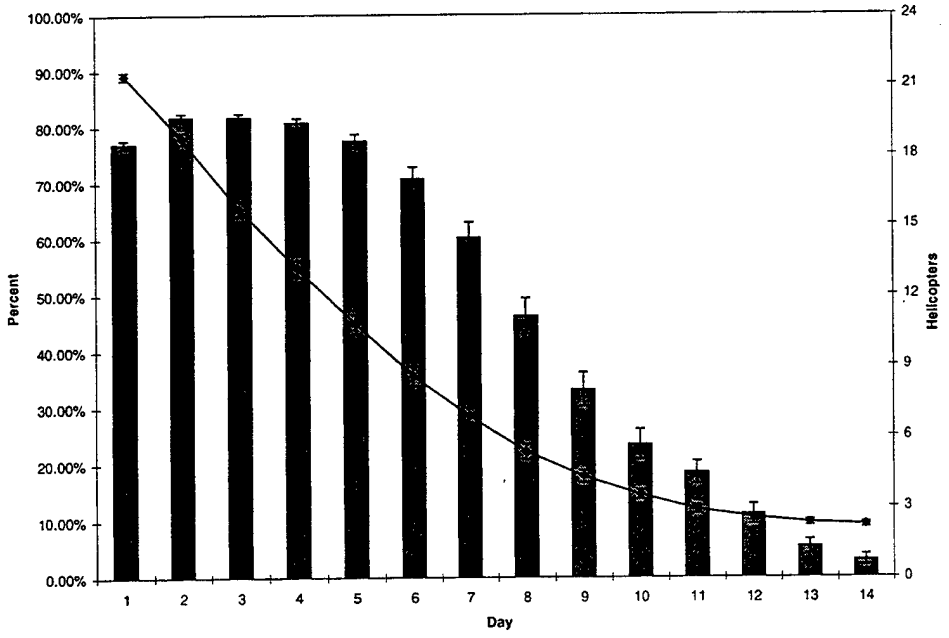

Figure 50. MOEs for Model with a Non-homogeneous Failure Rate Process. This graph shows the effects on the results for the model using a non-homogeneous Poisson process to generate times between mission-affecting failures.

B. ANALYSIS OF A LOWER FATALITY RATE FOR MISSION-AFFECTING FAILURES

Recent analysis of historical data for the percentage of mission-affecting failures resulting in a fatality has resulted in an estimate of approximately 1% vice 10% as has been modeled previously. This section compares the two different percentages for fatal mission-affecting failures. The cases chosen for comparison are shown below in Table 18.

	% of Mission-Affecting Failures Resulting in Fatalities
Case I	10%
Case II	1%

Table 18. Description of the Percentage of Mission-Affecting Failures that are Fatal.

The other inputs, which remain constant, are as follows:

Numerical Illustration

⇒	24	Number of Helicopters
⇒	160	Speed of Helicopters (knots)
⇒	300	Time between Scheduled Maintenance Actions (flight hours)
⇒	40	High-Threat Vulnerability (Mean Time until a Helicopter is Shot Down in Region) (hours)
⇒	80	Low-Threat Vulnerability (Mean Time until a Helicopter is Shot Down in Region) (hours)
⇒	1	Repair Facilities
⇒	1	Scheduled Maintenance Facilities
⇒	1	Mean Time to Repair a Failure (hours-Exponentially Distributed)
⇒	0.25	Mean Time of Helicopter Turnaround (hours-Exponentially Distributed)
⇒	144-192	Minimum/Maximum Time to Complete Scheduled Maintenance (hours-Uniformly Distributed)
⇒	8.5	Mean Time between Mission-Affecting Failures (hours)
⇒	1.0	Shape of Weibull Distribution Modeling MAF

One hundred runs of the simulation were conducted for a two-week campaign to compare the results for the different percentages of fatal mission-affecting failures. Figure 51 and Figure 52 show the results of the simulations for the different percentages of mission-affecting failures resulting in fatalities. The graphs show that with the lower percentage of mission-affecting failures resulting in fatalities, the helicopters are able to provide increased coverage for a longer period of time. With 1% of the mission-affecting failures ending in a fatality, the helicopters are able to maintain a mean percent coverage of the NAI greater than 80% for a week. The mean number of helicopters does not decline as rapidly for the 1-percent case either. At the end of the 2-week campaign the mean number of helicopters surviving is 4.22 while still maintaining a mean percent coverage per day of almost 24%. The percentage of mission-affecting failures ending fatally needs to be addressed and considered during an operational test. A variation in this parameter can produce dramatic effects on the performance of the system being evaluated.

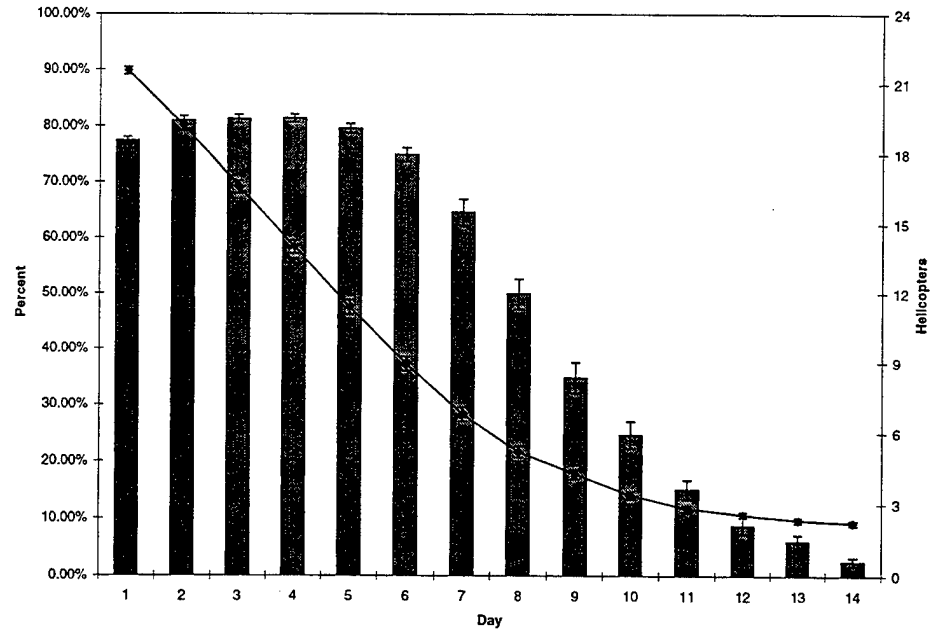

Figure 51. MOEs with 10% of Mission-Affecting Failures Resulting in Fatalities. Case I from Table 18 that shows the effects for 10% of mission-affecting failures resulting in fatalities on the mean percent coverage and the mean number of helicopters surviving.

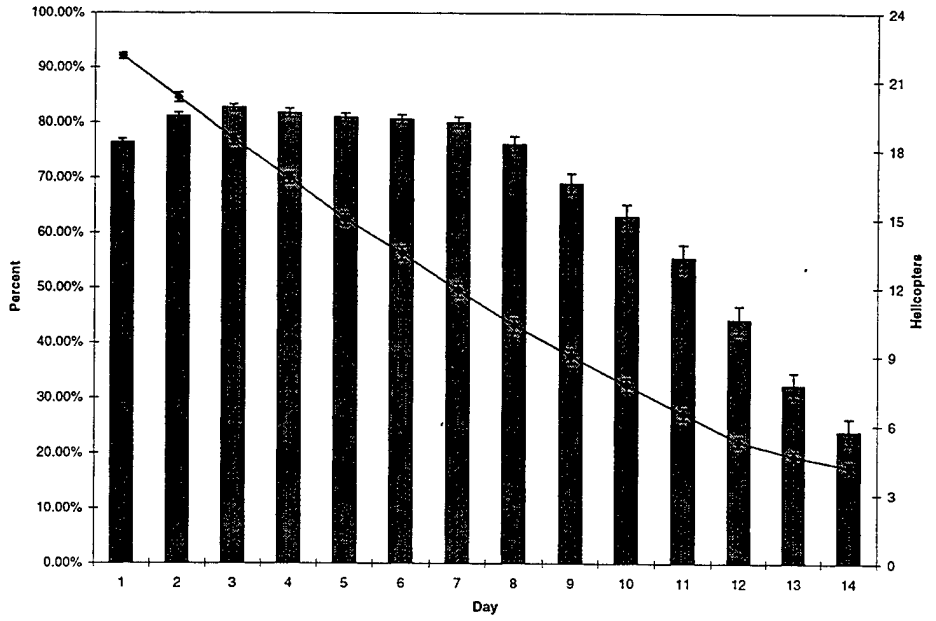

Figure 52. MOEs with 1% of Mission-Affecting Failures Resulting in Fatalities. Case II from Table 18 that shows the effects with 1% of mission-affecting failures resulting in fatalities on the mean percent coverage and the mean number of helicopters surviving.

C. COMPARISONS BETWEEN THE COMANCHE AND THE KIOWA WARRIOR

The RAH-66 Comanche is being acquired to replace the OH-58D Kiowa Warrior. A big question that is always asked when purchasing a new weapon system to replace an older system is, "How does the new system compare to the old system?" Using the simulation, and changing the parameters to fit those of the Kiowa Warrior, a comparison between the two weapon systems can be made.

In performing these comparisons, the assumption was made that the Comanche was twice as stealthy as the Kiowa Warrior. This results in the vulnerability rates for the Comanche being half that of the Kiowa Warrior. It was assumed for the simulation that except for the speed and vulnerability of the helicopters the other parameters are the same for the two helicopters. The different parameters for each helicopter are shown below in Table 19.

	Speed	Mean Time until a Helicopter is Shot Down while in a Low Vulnerability Region	Mean Time until a Helicopter is Shot Down while in a High Vulnerability Region
Comanche	160 Knots	320 Hours	160 Hours
Kiowa Warrior	110 Knots	160 Hours	80 Hours

Table 19. Description of Differences between Two Helicopter Systems.

The other inputs, which remain constant, are as follows:

Numerical Illustration

⇒	24	Number of Helicopters
⇒	300	Time between Scheduled Maintenance Actions (flight hours)
⇒	1	Repair Facilities
⇒	1	Scheduled Maintenance Facilities
⇒	1	Mean Time to Repair a Failure (hours-Exponentially Distributed)
⇒	0.25	Mean Time of Helicopter Turnaround (hours-Exponentially Distributed)
⇒	144-192	Minimum/Maximum Time to Complete Scheduled Maintenance (hours-Uniformly Distributed)
⇒	8.5	Mean Time between Mission-Affecting Failures (hours)
⇒	1.0	Shape of Weibull Distribution Modeling MAF
⇒	0.1	Probability of a failure being fatal (Crash)

One hundred runs of the simulation were conducted for a two-week campaign to compare the effects on the MOEs for the two different helicopters. Figure 53 and Figure 54 show the results of the simulations. It is apparent that the Comanche helicopter outperforms the Kiowa Warrior in this scenario. The Kiowa Warrior is able to maintain mean coverage of the NAI above 50% for about 6 days, while the Comanche is able to maintain mean coverage of the NAI above 50% for over 13 days. During the last week of the campaign, the Kiowa Warrior provides very little mean coverage, while the Comanche is able to provide nominal mean coverage that never drops below 12%. Another large difference between the two helicopters is the mean number of helicopters surviving. The Comanche finished the campaign with a mean of 3.66 helicopters surviving, while the Kiowa Warrior finished with a mean of 2.53 helicopters. This may not seem like a big difference; but in the last week, the Comanche on average, lost almost as many helicopters as the Kiowa Warrior was able to keep alive. The Comanche still finished the campaign with a greater mean number of helicopters surviving than did the Kiowa Warrior.

The reader is cautioned about placing too much emphasis on this one scenario. The simulation operates both helicopters according to the same tactics, but in reality there is nothing that say the helicopters must be operated in the same manner to accomplish the mission. It is possible that other tactics may be employed by the Kiowa Warrior that would allow it to outperform the Comanche. This is just one scenario to illustrate the use of the simulation to aid in side-by-side testing of platforms.

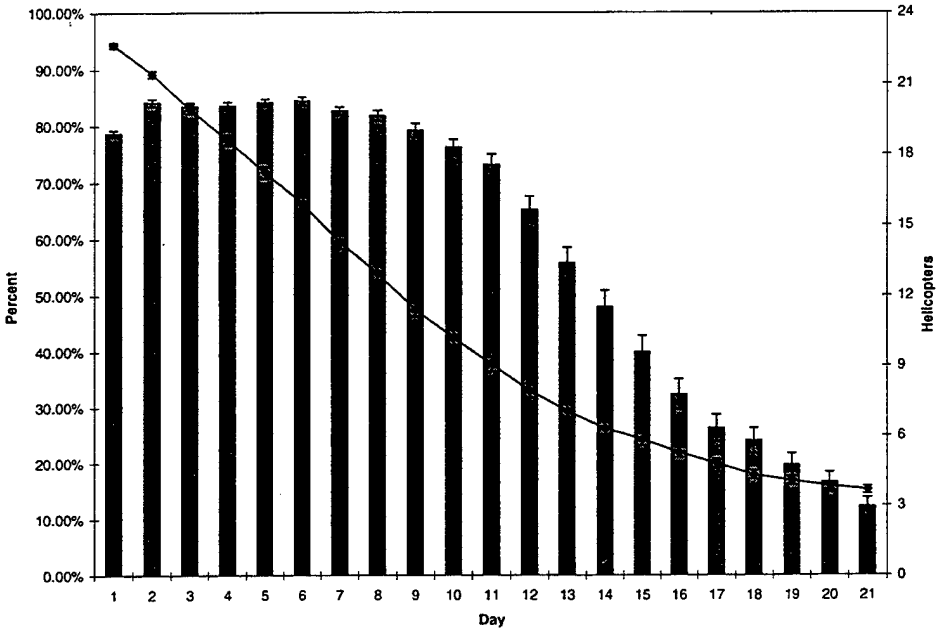

Figure 53. MOEs for the Comache Helicopter. This graph show the results of a simulation for the Comanche helicopter for a three-week campaign.

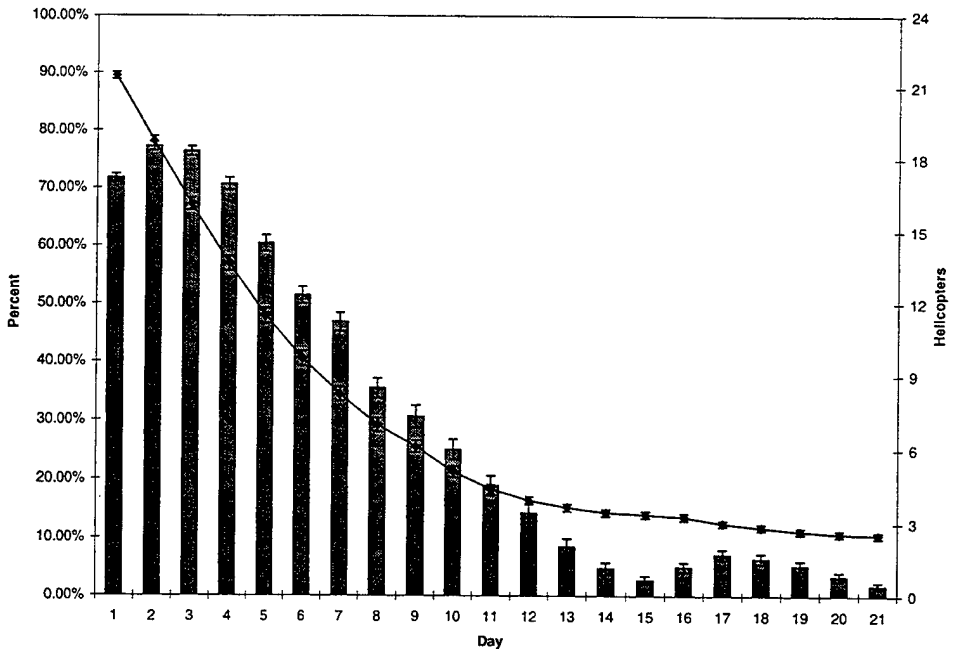

Figure 54. MOEs for the Kiowa Warrior Helicopter. This graph shows the results of a simulation for the Kiowa Warrior helicopter for a three-week campaign.

VII. CONCLUSIONS AND RECOMMENDATIONS

A. SUMMARY OF ANALYSIS

The analysis of the RAH-66 Comanche produced several insights about the operation and maintenance of the reconnaissance system. The insights gained are not just Comanche-specific, but rather can be extended to a variety of mobile reconnaissance systems.

A few of the parameter changes examined resulted in large variations in the measures of effectiveness for both models used in the analysis. The vulnerability of the reconnaissance platforms proved to have the largest effect on the MOEs in both models. Another parameter that resulted in dramatic changes in the output was the mean time between mission-affecting failures. The model utilizing independent identically distributed times between mission-affecting failures also indicated that the type of failures (i.e., infant or wear out) experienced was an important issue that should be addressed by T&E decision-makers. The previously mentioned parameters should all be addressed during actual field testing of the Comanche helicopter. The results produced changed dramatically for each variation of the parameters. These parameters and the physical and operational effects that they represent should be further analyzed and scrutinized to more accurately determine their effects on the operation and maintenance of the platform and the entire system.

Other parameters, such as the time between scheduled maintenance activities, the number of scheduled maintenance facilities, the overhaul times, and the aging effects

produced slight variations in the MOEs. These parameters deserve additional analysis. It is possible that the results observed for them are a result of the scenario chosen to represent a plausible mission for the analysis. Under another set of circumstances and mission characteristics, these parameters are likely to produce completely different results. The new results and conclusions may well indicate that the parameters do need to be addressed during operational testing.

Additionally, more analysis must be done on those parameters such as the number of repair facilities and priority maintenance, which did not produce any noticeable effect on the MOEs. The scenarios and/or other parameters should be adjusted so that the model is stressed with respect to the parameters being observed. Under new conditions and stresses, these parameters may prove to be interesting and warrant additional consideration in operational testing.

B. RECOMMENDATIONS

1. Model Improvement

Several improvements and additions to the simulation model can be incorporated for future studies. The current model only examines some of the aspects of moving the reconnaissance assets to and from a Named Area of Interest. An improvement would be to incorporate an analysis of events occurring while a helicopter pair reconnoiters the NAI. This should include an analysis of the sensors carried onboard the reconnaissance platforms by explicitly including the sensors in the model to represent sensing, detection, and identification of enemy units. Additional improvements include providing the ability

for armed reconnaissance platforms to react to a threat while transiting to and from the NAI, as well as incorporating a means for monitoring several NAIs at once.

2. Further Studies and Analysis

Current ongoing studies continue to analyze the capabilities and limitations of the RAH-66 Comanche helicopter. Future studies conducted, as a follow on to this thesis, will provide additional relevant information that may be incorporated into or even amplify the results of current studies. Additional study and analysis is needed concerning the sensor packages that are being incorporated into the Comanche helicopter. Specific items of study would include sensor failures (which are incorporated in the MTBMAF in this study), the capabilities of individual sensors, the combined capabilities of multiple sensors, the effects of any redundancy that may be incorporated into the sensor systems, and the interaction between the sensors and the platform. Additionally, the ability of a platform to communicate information obtained from its sensors to other assets working in conjunction with it, as well as commanders and other units in need of the acquired information, should also be studied using modeling and simulation. Any operation that employs a reconnaissance asset is also open to studies of the type described here.

C. CONCLUSIONS

This thesis has demonstrated the use of a simple, event-step, stochastic simulation to identify influential parameters involved in operating and maintaining a mobile reconnaissance system. Through the conduct of sensitivity analysis by varying input parameters to observe the effects on the output, influential parameters (and distributional

forms) were investigated. The influential parameters determined should be monitored and scrutinized during Operational Tests of the platform of interest.

The simulation was exercised by conducting sensitivity analysis on several input parameters that correspond to actual operational parameters for the RAH-66 Comanche helicopter. The analysis performed with the simulation can be used to aid in the preparation of the Test and Evaluation Master Plan (TEMP) and conduct of the Operational Test and Evaluation of the Comanche helicopter. Two hypothetical distribution models were used to represent the times between mission-affecting failures to show the versatility that can easily be incorporated into a simulation designed for use on a personal computer.

In addition to the above-mentioned application, the simulation can also be used to assist in the conduct of side-by-side testing of competing reconnaissance platforms by manipulating the input parameters to correspond to the competing platforms. Another possible application for its use would be to analyze the capabilities of different sized units to provide information for force structure decisions.

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APPENDIX A: ANALYTICAL MODELS FOR COMPARISON

In order to check the validity of the simulation model, a comparison was made to analytical models developed by Professor Patricia A. Jacobs. The analytical models calculate the expected time spent by an individual helicopter over the high-threat region given that it entered the high-threat region, and the probability of an individual helicopter returning to its home base given that it started a mission. Exponential distributions were assumed for all times to failures and repairs.

Parameters:

λ = Rate of all Mission-affecting Failures
λ_0 = Rate of Non-fatal Mission-affecting Failures
λ_f = Rate of Fatal Mission-affecting Failures
κ_0 = Kill Rate over Ingress Route (attrition and crashes)—Low Threat Region
κ_1 = Kill Rate over Egress Route (attrition and crashes)—Low Threat Region
κ_2 = Kill Rate in High Threat Area (attrition and crashes)—High Threat Region
τ_0 = Ingress Time (hours)
τ_1 = Egress Time (hours)
τ_2 = Time in High Threat Region (hours)

In order to compare the analytical models to the simulation, the values for each of the parameters are set equal to the corresponding value in the simulation. The rate of non-fatal mission-affecting failures (λ_0) is equal to the percentage of mission-affecting failures that are non-fatal (here assumed to be 90%) multiplied by the mission-affecting failure rate ($\lambda = 1/8.5$). The fatal mission-affecting failure rate is calculated in the same fashion. The kill rates for each region are calculated by taking the inverse of the mean time until an individual helicopter is shot down in the respective region. The values for each of the parameters are listed below.

$\lambda = 0.1176$ Rate of all Mission-affecting Failures
$\lambda_0 = 0.1059$ Rate of Non-fatal Mission-affecting Failures
$\lambda_f = 0.01176$ Rate of Fatal Mission-affecting Failures
$\kappa 0 = 0.0125$ Kill Rate over Ingress Route (attrition)—Low Threat Region
$\kappa 1 = 0.0125$ Kill Rate over Egress Route (attrition)—Low Threat Region
$\kappa 2 = 0.025$ Kill Rate in High Threat Area (attrition)—High Threat Region
$\tau 0 = 0.5675$ Ingress Time (hours)
$\tau 1 = 0.4156$ Egress Time (hours)
$\tau 2 = 2.0169$ Time in High Threat Region (hours)

Conditional Expected Time Over High Threat Region|Given the High Threat Region Was Entered =

$$\left[\frac{(1-\exp(-(\lambda+\kappa_2)\tau_2))}{(\lambda+\kappa_2)}\right]$$

Equation (A-1)

Probability of Mission Survival =

$$\underbrace{\left[\frac{\lambda_0}{\lambda+\lambda_f+2\kappa_0}\left(1-\exp\left(-\left(\lambda+\lambda_f+2\kappa_0\right)\tau_0\right)\right)\right]}_{\text{Probability that a mission - affecting failure occurs during ingress and platform returns to base.}}$$

$$+\underbrace{\left[\exp\left(-\left(\lambda+\kappa_0\right)\tau_0\right)\frac{\lambda_0}{\lambda+\kappa_2}\exp(-(\lambda_f+\kappa_1)\tau_1)\left(1-\exp\left(-\left(\lambda+\kappa_2\right)\tau_2\right)\right)\right]}_{\text{Probability that a mission - affecting failure occurs in the high threat region and platform returns to base.}}$$

$$+\underbrace{\left[\exp(-(\lambda+\kappa_0)\tau_0)\exp(-(\lambda+\kappa_2)\tau_2)\exp(-(\lambda_f+\kappa_1)\tau_1\left(1-\exp\left(-\lambda_0\tau_1\right)\right)\right]}_{\text{Probability that a mission - affecting failure occurs during egress and platform returns to base.}}$$

$$+\underbrace{\left[\exp\left(-(\lambda+\kappa_0)\tau_0\right)\exp(-\left(\lambda+\kappa_2\right)\tau_2)\exp(-\left(\lambda+\kappa_1\right)\tau_1)\right]}_{\text{Probability that no events occur during the mission flight.}}$$

Equation (A-2)

The results from the simulation and the analytical models are shown below in Table 20 and add credibility to the validity of the simulation results. In the simulation helicopters move via waypoints when no failures occur, but when a failure occurs, the helicopter returns to the home base via the most direct route. Thus the time it takes to leave an area because of a failure will be somewhat less than the time it took to get into the area. Therefore, and as expected, the simulated probability of return to the home base will be slightly greater than that for the analytical model.

The simulated expected time over the high threat region is slightly higher than the analytical model because of an assumption made in the analytical model. If a helicopter fails while in the high threat region, it immediately and instantaneously moves to the egress route, which is located in a low threat region. The simulation must (realistically) fly each helicopter out of the high threat region if it experiences a mission-affecting failure. This additional time in the high threat region for the simulation model accounts for the difference in the expected time over the high-threat region between the two models.

	Simulation	Analytical Model
Probability of Returning to Home Base given a Helicopter Launch	0.927 (0.0046)	0.918
Expected Time Over High-Threat Region during a Mission given High-Threat Region was Entered	1.774 (0.005) Hours	1.753 Hours

Table 20. Comparison of Simulation and Analytical Models.

APPENDIX B: SIMULATION DATA OUTPUT FOR WEIBULL DISTRIBUTION

The following tables list extended output results from each of the simulations conducted for this thesis: They summarize measures of variability between hypothetical campaigns (100 campaigns/replications).

	Coverage					Helicopters				
	Percentiles							Percentiles		
Day	25%	50%	75%	se	Percent Coverage	Surviving Helos	se	25%	50%	75%
1	72.42%	78.04%	81.99%	0.63%	77.37%	21.56	0.16	21	22	23
2	75.31%	80.70%	86.65%	0.79%	80.96%	19.2	0.22	17	20	21
3	77.08%	80.97%	86.26%	0.72%	81.28%	16.59	0.27	15	17	18
4	77.41%	82.14%	85.61%	0.70%	81.38%	14.01	0.28	13	14	16
5	74.75%	80.94%	84.77%	0.85%	79.60%	11.4	0.33	9	12	14
6	69.67%	77.67%	84.12%	1.26%	74.92%	8.96	0.31	7	9	11
7	52.69%	71.45%	82.37%	2.36%	64.64%	6.79	0.30	4	6.5	9
8	33.47%	53.14%	73.72%	2.69%	49.92%	5.21	0.24	3	5	7
9	9.66%	33.02%	57.20%	2.74%	34.83%	4.27	0.20	3	4	6
10	0.00%	20.66%	39.82%	2.36%	24.72%	3.39	0.16	2	3	5
11	0.00%	7.78%	26.86%	1.69%	15.09%	2.83	0.13	2	2	4
12	0.00%	0.00%	14.33%	1.41%	8.83%	2.57	0.11	2	2	3
13	0.00%	0.00%	6.97%	1.15%	6.09%	2.35	0.11	1.75	2	3
14	0.00%	0.00%	0.00%	0.71%	2.56%	2.23	0.10	1	2	3

Total Runs	100	
Mean Number of MAF per Campaign of 14.0 Days	81.28	
Mean Number of Fatal Failures (Crashes) per Campaign of 14.0 Days	8.1	
Mean Number of Helicopters Lost to Enemy Action per Campaign of 14.0 Days	13.67	
Mean Repair and Turnaround Time per Entry into the Repair System	0.511009	0.004458
Mean Missions Started per campaign of 14.0 Days	150.66	
Prob of Returning to Base Safely given started a mission	0.927751	
Mean Time in High Threat Region per Helicopter per Campaign of 14.0Days	17.3114	
Mean Time in High Threat Region per Entry	1.597238	0.003787
Scheduled Time in High Threat Region	2.01686	
Mean Number of Times Individual Helicopters entered High Threat Region per Campaign of 14.0 Days	260.12	
Mean Survival Time of Individual Helicopters per Campaign of 14.0 Days	131.9227	1.925418
Mean Number of Helicopters in Repair System per hour per Campaign of 14.0 Days	1.091719	0.03096

Table 21. Data for Figure 3, Figure 9, Figure 13, Figure 17, Figure 18, and Figure 21.

	Coverage					Helicopters				
	Percentiles							Percentiles		
Day	25%	50%	75%	se	Percent Coverage	Surviving Helos	se	25%	50%	75%
1	62.45%	67.38%	71.47%	0.67%	67.23%	20.13	0.20	19	20	22
2	76.72%	81.24%	85.18%	0.66%	80.79%	16.95	0.24	15	17	19
3	76.53%	81.95%	86.66%	0.79%	81.30%	14.1	0.29	12	14	16
4	76.05%	81.81%	87.55%	1.03%	80.31%	11.27	0.32	9	11	13
5	66.04%	77.83%	85.36%	1.32%	76.31%	8.81	0.31	7	8.5	11
6	49.99%	67.47%	82.95%	1.96%	65.86%	6.87	0.29	5	7	8.25
7	40.94%	59.34%	73.31%	2.57%	55.59%	5.46	0.26	3	5	7
8	19.13%	42.22%	65.14%	2.94%	41.18%	4.29	0.20	3	4	5
9	0.00%	29.71%	48.07%	2.68%	29.64%	3.59	0.18	2	3	5
10	0.00%	13.69%	33.88%	2.14%	18.86%	2.93	0.15	2	3	4
11	0.00%	1.08%	25.66%	1.77%	13.05%	2.52	0.13	2	2	3
12	0.00%	0.00%	8.54%	1.57%	8.58%	2.26	0.11	1	2	3
13	0.00%	0.00%	0.00%	1.24%	5.29%	2.1	0.10	1	2	3
14	0.00%	0.00%	0.00%	1.24%	4.06%	1.98	0.09	1	2	3

Total Runs	100	
Mean Number of MAF per Campaign of 14.0 Days	95.52	
Mean Number of Fatal Failures (Crashes) per Campaign of 14.0 Days	9.42	
Mean Number of Helicopters Lost to Enemy Action per Campaign of 14.0 Days	12.6	
Mean Repair and Turnaround Time per Entry into the Repair System	0.558162	0.005323
Mean Missions Started per campaign of 14.0 Days	147.21	
Prob of Returning to Base Safely given started a mission	0.925209	
Mean Time in High Threat Region per Helicopter per Campaign of 14.0Days	15.89311	
Mean Time in High Threat Region per Entry	1.617756	0.003979
Scheduled Time in High Threat Region	2.01686	
Mean Number of Times Individual Helicopters entered High Threat Region per Campaign of 14.0 Days	235.78	
Mean Survival Time of Individual Helicopters per Campaign of 14.0 Days	113.8934	1.943627
Mean Number of Helicopters in Repair System per hour per Campaign of 14.0 Days	1.714299	0.063173

Table 22. Data for Figure 4.

	Coverage					Helicopters				
	Percentiles							Percentiles		
Day	25%	50%	75%	se	Percent Coverage	Surviving Helos	se	25%	50%	75%
1	83.46%	86.29%	89.31%	0.47%	86.22%	21.92	0.14	21	22	23
2	79.37%	84.62%	89.03%	0.67%	84.23%	19.47	0.22	18	19	21
3	76.60%	81.54%	84.66%	0.66%	81.18%	16.59	0.26	15	17	18
4	77.53%	81.87%	85.44%	0.66%	81.19%	13.95	0.29	12	14	16
5	74.62%	80.87%	84.82%	0.93%	79.05%	11.29	0.31	9.75	11.5	13
6	69.28%	76.72%	82.05%	1.56%	73.07%	8.86	0.32	7	9	10.25
7	54.21%	65.29%	78.98%	2.13%	63.33%	6.86	0.31	5	6	9
8	31.54%	45.83%	71.16%	2.60%	47.47%	5.2	0.23	3.75	5	7
9	9.39%	34.76%	47.67%	2.46%	33.08%	4.2	0.18	3	4	5
10	5.06%	22.03%	35.77%	1.93%	22.51%	3.41	0.15	2.75	3	4
11	0.00%	13.73%	31.95%	1.81%	17.84%	2.85	0.13	2	3	4
12	0.00%	0.00%	16.42%	1.52%	10.09%	2.54	0.12	2	2	3
13	0.00%	0.00%	0.00%	1.12%	5.28%	2.43	0.11	2	2	3
14	0.00%	0.00%	0.00%	0.92%	3.66%	2.29	0.11	2	2	3

Total Runs	100	
Mean Number of MAF per Campaign of 14.0 Days	75.14	
Mean Number of Fatal Failures (Crashes) per Campaign of 14.0 Days	7.46	
Mean Number of Helicopters Lost to Enemy Action per Campaign of 14.0 Days	14.25	
Mean Repair and Turnaround Time per Entry into the Repair System	0.49884	0.004345
Mean Missions Started per campaign of 14.0 Days	146.93	
Prob of Returning to Base Safely given started a mission	0.926121	
Mean Time in High Threat Region per Helicopter per Campaign of 14.0Days	17.42838	
Mean Time in High Threat Region per Entry	1.611129	0.003711
Scheduled Time in High Threat Region	2.01686	
Mean Number of Times Individual Helicopters entered High Threat Region per Campaign of 14.0 Days	259.62	
Mean Survival Time of Individual Helicopters per Campaign of 14.0 Days	132.5984	1.913532
Mean Number of Helicopters in Repair System per hour per Campaign of 14.0 Days	0.978329	0.027694

Table 23. Data for Figure 5.

	Coverage					Helicopters				
	Percentiles							Percentiles		
Day	25%	50%	75%	se	Percent Coverage	Surviving Helos	se	25%	50%	75%
1	75.31%	78.74%	82.50%	0.55%	78.72%	22.64	0.11	22	23	23
2	79.88%	83.64%	89.02%	0.64%	84.25%	21.42	0.15	20	21.5	23
3	79.72%	84.47%	87.62%	0.67%	83.52%	19.93	0.20	19	20	21
4	79.22%	83.58%	87.53%	0.66%	83.65%	18.6	0.22	17	19	20
5	80.09%	84.93%	88.70%	0.63%	84.20%	17.22	0.26	16	17	19
6	80.61%	84.95%	89.36%	0.65%	84.48%	15.91	0.27	14	16	18
7	77.43%	83.75%	87.70%	0.71%	82.69%	14.28	0.29	12	15	16
8	76.03%	84.19%	88.75%	0.93%	81.83%	12.95	0.30	11	13	15
9	75.73%	81.72%	86.81%	1.20%	79.25%	11.41	0.30	10	11	13
10	67.23%	79.61%	86.23%	1.43%	76.22%	10.21	0.32	8	10	13
11	65.08%	78.36%	87.22%	1.89%	73.18%	9.06	0.31	7	9	11
12	52.96%	71.22%	83.70%	2.35%	65.18%	7.93	0.32	5	8	10
13	36.51%	63.37%	79.22%	2.76%	55.79%	7.05	0.28	5	7	9
14	28.05%	53.70%	71.22%	2.95%	48.04%	6.31	0.27	4	6	8
15	12.27%	39.98%	67.14%	2.92%	39.98%	5.83	0.25	4	5	7
16	0.00%	33.79%	51.29%	2.73%	32.38%	5.27	0.22	4	5	6
17	0.00%	28.64%	41.33%	2.44%	26.34%	4.78	0.19	3.75	5	6
18	0.00%	23.40%	41.20%	2.25%	24.11%	4.31	0.18	3	4	5
19	0.00%	13.96%	36.14%	2.04%	19.71%	4.05	0.17	3	4	5
20	0.00%	11.18%	34.04%	1.81%	16.65%	3.83	0.17	3	4	5
21	0.00%	0.00%	27.47%	1.66%	12.23%	3.66	0.17	3	3	5

Total Runs	100	
Mean Number of MAF per Campaign of 21.0 Days	143.01	
Mean Number of Fatal Failures (Crashes) per Campaign of 21.0 Days	14.14	
Mean Number of Helicopters Lost to Enemy Action per Campaign of 21.0 Days	6.2	
Mean Repair and Turnaround Time per Entry into the Repair System	0.509688	0.003339
Mean Missions Started per campaign of 21.0 Days	259.82	
Prob of Returning to Base Safely given started a mission	0.960858	
Mean Time in High Threat Region per Helicopter per Campaign of 21.0Days	31.16501	
Mean Time in High Threat Region per Entry	1.651637	0.002742
Scheduled Time in High Threat Region	2.01686	
Mean Number of Times Individual Helicopters entered High Threat Region per Campaign of 21.0 Days	452.86	
Mean Survival Time of Individual Helicopters per Campaign of 21.0 Days	236.6388	3.227454
Mean Number of Helicopters in Repair System per hour per Campaign of 21.0 Days	1.328528	0.032346

Table 24. Data for Figure 6.

	Coverage					Helicopters				
	Percentiles							Percentiles		
Day	25%	50%	75%	se	Percent Coverage	Surviving Helos	se	25%	50%	75%
1	73.26%	77.98%	81.99%	0.61%	77.78%	22.23	0.13	22	22	23
2	77.83%	82.36%	86.50%	0.63%	82.10%	20.21	0.18	19	20	21
3	79.50%	82.69%	87.91%	0.63%	83.28%	18.3	0.23	17	18	20
4	78.25%	82.98%	87.49%	0.66%	82.65%	16.42	0.26	15	17	18
5	79.80%	83.47%	87.27%	0.63%	83.54%	14.75	0.31	13	16	17
6	78.68%	82.76%	85.60%	0.79%	81.71%	12.94	0.32	11	13	15.25
7	75.82%	82.32%	86.99%	0.93%	80.81%	11.19	0.33	9	11.5	14
8	69.12%	81.18%	86.92%	1.73%	75.11%	9.54	0.35	7	10	12
9	53.06%	71.11%	82.34%	2.16%	66.79%	8.29	0.34	6	8	11
10	41.12%	68.94%	81.11%	2.69%	59.86%	6.98	0.31	4.75	7	8.25
11	32.20%	49.69%	66.00%	2.59%	48.75%	5.91	0.29	4	6	7
12	22.52%	41.76%	60.87%	2.72%	41.59%	5.04	0.26	3	5	6
13	0.00%	31.73%	44.02%	2.65%	30.30%	4.42	0.22	3	4	6
14	0.00%	23.48%	41.20%	2.40%	23.67%	3.99	0.18	3	4	5
15	0.00%	0.00%	32.37%	2.14%	15.96%	3.56	0.16	2	4	4.25
16	0.00%	0.00%	15.08%	1.80%	10.25%	3.45	0.15	2	3.5	4
17	0.00%	0.00%	14.14%	1.37%	9.78%	3.16	0.14	2	3	4
18	0.00%	0.00%	20.60%	1.61%	11.12%	2.96	0.14	2	3	4
19	0.00%	0.00%	19.10%	1.57%	10.78%	2.75	0.14	2	3	4
20	0.00%	0.00%	2.87%	1.19%	6.24%	2.6	0.13	1	3	3
21	0.00%	0.00%	0.00%	1.24%	5.16%	2.52	0.13	1	2.5	3

Total Runs	100	
Mean Number of MAF per Campaign of 21.0 Days	115.05	
Mean Number of Fatal Failures (Crashes) per Campaign of 21.0 Days	11.46	
Mean Number of Helicopters Lost to Enemy Action per Campaign of 21.0 Days	10.02	
Mean Repair and Turnaround Time per Entry into the Repair System	0.50974	0.003723
Mean Missions Started per campaign of 21.0 Days	210.64	
Prob of Returning to Base Safely given started a mission	0.949013	
Mean Time in High Threat Region per Helicopter per Campaign of 21.0Days	24.97815	
Mean Time in High Threat Region per Entry	1.636928	0.003079
Scheduled Time in High Threat Region	2.01686	
Mean Number of Times Individual Helicopters entered High Threat Region per Campaign of 21.0 Days	366.22	
Mean Survival Time of Individual Helicopters per Campaign of 21.0 Days	191.8066	3.016142
Mean Number of Helicopters in Repair System per hour per Campaign of 21.0 Days	1.025909	0.028804

Table 25. Data for Figure 7.

	Coverage					Helicopters				
	Percentiles							Percentiles		
Day	25%	50%	75%	se	Percent Coverage	Surviving Helos	se	25%	50%	75%
1	71.56%	75.89%	80.66%	0.62%	75.85%	21.36	0.16	20	21	23
2	76.67%	81.54%	86.05%	0.67%	81.53%	18.79	0.21	17.75	19	20
3	78.51%	82.15%	86.24%	0.66%	81.76%	16.31	0.24	15	16.5	18
4	77.38%	82.63%	86.28%	0.66%	82.27%	13.69	0.27	12	13.5	16
5	76.31%	80.91%	84.86%	0.90%	79.63%	11.06	0.31	9	11	12.25
6	67.40%	76.61%	83.77%	1.21%	74.04%	8.57	0.29	7	8	10
7	57.03%	67.23%	78.90%	1.86%	64.99%	6.62	0.29	4	6	8
8	34.28%	45.29%	69.84%	2.42%	49.70%	5.15	0.27	3	4	6.25
9	8.56%	29.04%	43.10%	2.52%	30.64%	4.18	0.23	3	4	5
10	0.00%	12.60%	34.15%	2.44%	20.82%	3.46	0.18	2	3	4
11	0.00%	11.99%	27.83%	1.90%	16.43%	2.85	0.14	2	3	3
12	0.00%	0.00%	16.51%	1.47%	9.49%	2.53	0.11	2	2	3
13	0.00%	0.00%	0.00%	1.18%	5.36%	2.34	0.10	2	2	3
14	0.00%	0.00%	0.00%	0.92%	2.87%	2.27	0.10	2	2	3
15	0.00%	0.00%	0.00%	0.96%	3.37%	2.2	0.09	2	2	3
16	0.00%	0.00%	0.00%	0.65%	2.35%	2.1	0.09	1	2	3
17	0.00%	0.00%	6.87%	0.86%	4.38%	1.95	0.09	1	2	2
18	0.00%	0.00%	6.87%	1.18%	6.21%	1.78	0.09	1	2	2
19	0.00%	0.00%	7.14%	1.08%	5.61%	1.59	0.08	1	1	2
20	0.00%	0.00%	0.00%	0.99%	3.52%	1.51	0.08	1	1	2
21	0.00%	0.00%	0.00%	0.79%	2.52%	1.47	0.08	1	1	2

Total Runs	100	
Mean Number of MAF per Campaign of 21.0 Days	84.26	
Mean Number of Fatal Failures (Crashes) per Campaign of 21.0 Days	8.35	
Mean Number of Helicopters Lost to Enemy Action per Campaign of 21.0 Days	14.18	
Mean Repair and Turnaround Time per Entry into the Repair System	0.510947	0.004387
Mean Missions Started per campaign of 21.0 Days	155.77	
Prob of Returning to Base Safely given started a mission	0.927682	
Mean Time in High Threat Region per Helicopter per Campaign of 21.0Days	17.84127	
Mean Time in High Threat Region per Entry	1.596653	0.003724
Scheduled Time in High Threat Region	2.01686	
Mean Number of Times Individual Helicopters entered High Threat Region per Campaign of 21.0 Days	268.18	
Mean Survival Time of Individual Helicopters per Campaign of 21.0 Days	142.676	2.600398
Mean Number of Helicopters in Repair System per hour per Campaign of 21.0 Days	0.735119	0.019189

Table 26. Data for Figure 8.

	Coverage					Helicopters				
	Percentiles							Percentiles		
Day	25%	50%	75%	se	Percent Coverage	Surviving Helos	se	25%	50%	75%
1	73.47%	77.22%	80.99%	0.61%	77.04%	21.55	0.14	21	22	23
2	75.89%	81.20%	86.61%	0.69%	81.56%	19.07	0.23	18	19	21
3	77.70%	82.31%	85.88%	0.63%	81.70%	16.34	0.28	14	16	18
4	77.63%	82.30%	87.31%	0.63%	81.98%	14.11	0.31	12	14	16
5	77.50%	83.35%	86.54%	0.86%	81.25%	11.37	0.35	9	11	13
6	71.23%	79.90%	86.02%	1.39%	76.52%	9.04	0.36	6	9	11
7	56.51%	71.63%	82.35%	2.12%	66.23%	6.95	0.33	4	7	9
8	39.57%	57.98%	71.72%	2.51%	52.83%	5.05	0.27	3	5	7
9	0.00%	36.03%	57.20%	2.79%	34.84%	3.87	0.23	2	3	5
10	0.00%	15.04%	37.63%	2.42%	21.94%	3.17	0.19	2	3	4
11	0.00%	6.87%	30.81%	2.03%	16.60%	2.63	0.16	2	2	3
12	0.00%	0.00%	17.36%	1.69%	11.17%	2.24	0.13	1	2	3
13	0.00%	0.00%	6.87%	1.29%	6.89%	1.91	0.10	1	2	2
14	0.00%	0.00%	0.00%	0.98%	2.89%	1.81	0.09	1	2	2

Total Runs	100	
Mean Number of MAF per Campaign of 14.0 Days	81.88	
Mean Number of Fatal Failures (Crashes) per Campaign of 14.0 Days	8.04	
Mean Number of Helicopters Lost to Enemy Action per Campaign of 14.0 Days	14.15	
Mean Repair and Turnaround Time per Entry into the Repair System	0.50788	0.004401
Mean Missions Started per campaign of 14.0 Days	153.54	
Prob of Returning to Base Safely given started a mission	0.927739	
Mean Time in High Threat Region per Helicopter per Campaign of 14.0Days	17.58288	
Mean Time in High Threat Region per Entry	1.603058	0.003761
Scheduled Time in High Threat Region	2.01686	
Mean Number of Times Individual Helicopters entered High Threat Region per Campaign of 14.0 Days	263.24	
Mean Survival Time of Individual Helicopters per Campaign of 14.0 Days	129.881	1.87038
Mean Number of Helicopters in Repair System per hour per Campaign of 14.0 Days	1.093224	0.031916

Table 27. Data for Figure 10.

	Coverage					Helicopters				
	Percentiles							Percentiles		
Day	25.00%	50.00%	75.00%	se	Percent Coverage	Surviving Helos	se	25.00%	50.00%	75.00%
1	72.15%	75.62%	80.30%	0.57%	76.50%	21.56	0.17	21	22	23
2	77.50%	81.47%	85.51%	0.65%	81.16%	18.85	0.22	18	19	20
3	79.32%	84.37%	87.32%	0.61%	83.39%	16.29	0.26	15	17	18
4	76.34%	81.35%	86.49%	0.70%	81.46%	13.85	0.30	12	14	16
5	78.24%	81.62%	86.66%	0.80%	81.57%	11.53	0.34	9	12	14
6	72.69%	81.26%	86.66%	1.35%	77.53%	9.09	0.35	7	9.5	11
7	56.88%	72.51%	81.29%	1.97%	67.17%	7.05	0.33	5	7	9
8	36.38%	62.34%	74.56%	2.62%	54.78%	5.04	0.30	3	5	6.25
9	18.89%	40.74%	61.57%	2.75%	39.87%	3.69	0.23	2	3	5
10	0.00%	24.99%	41.78%	2.64%	25.99%	2.84	0.17	2	2	4
11	0.00%	0.00%	28.37%	1.98%	14.21%	2.33	0.13	1	2	3
12	0.00%	0.33%	21.54%	1.56%	11.47%	1.89	0.11	1	2	3
13	0.00%	0.00%	7.82%	1.31%	7.48%	1.62	0.09	1	1	2
14	0.00%	0.00%	0.00%	1.02%	3.44%	1.51	0.07	1	1	2

Total Runs	100	
Mean Number of MAF per Campaign of 14.0 Days	83.77	
Mean Number of Fatal Failures (Crashes) per Campaign of 14.0 Days	8.27	
Mean Number of Helicopters Lost to Enemy Action per Campaign of 14.0 Days	14.22	
Mean Repair and Turnaround Time per Entry into the Repair System	0.508949	0.004364
Mean Missions Started per campaign of 14.0 Days	156.1	
Prob of Returning to Base Safely given started a mission	0.927963	
Mean Time in High Threat Region per Helicopter per Campaign of 14.0Days	17.90625	
Mean Time in High Threat Region per Entry	1.601394	0.003719
Scheduled Time in High Threat Region	2.01686	
Mean Number of Times Individual Helicopters entered High Threat Region per Campaign of 14.0 Days	268.36	
Mean Survival Time of Individual Helicopters per Campaign of 14.0 Days	128.1642	1.825705
Mean Number of Helicopters in Repair System per hour per Campaign of 14.0 Days	1.124213	0.032688

Table 28. Data for Figure 11.

	Coverage					Helicopters				
	Percentiles							Percentiles		
Day	25%	50%	75%	se	Percent Coverage	Surviving Helos	se	25%	50%	75%
1	60.90%	65.27%	68.60%	0.69%	65.25%	20.61	0.19	19	21	22
2	64.50%	68.77%	74.98%	0.80%	69.66%	17.17	0.27	15	18	19
3	63.95%	68.87%	76.21%	0.92%	69.41%	14.02	0.30	12	14	16
4	50.06%	63.21%	69.33%	1.31%	60.02%	10.86	0.32	8	11	13
5	39.04%	49.89%	61.59%	1.52%	48.84%	8.2	0.30	6	8	11
6	26.25%	42.32%	52.53%	1.74%	39.87%	6.38	0.28	4	6	8
7	20.76%	32.68%	43.97%	1.75%	31.04%	4.86	0.24	3	5	6.25
8	1.06%	22.83%	36.15%	1.68%	22.07%	3.9	0.22	2	4	5
9	0.00%	10.34%	26.87%	1.83%	15.54%	3.2	0.18	2	3	4
10	0.00%	1.82%	14.94%	1.43%	9.96%	2.7	0.15	2	2	3
11	0.00%	0.00%	9.38%	1.20%	7.10%	2.17	0.12	1	2	3
12	0.00%	0.00%	0.41%	1.15%	4.54%	1.97	0.10	1	2	3
13	0.00%	0.00%	0.00%	0.89%	3.17%	1.83	0.09	1	2	2
14	0.00%	0.00%	0.00%	0.73%	2.64%	1.74	0.09	1	2	2

Total Runs	100	
Mean Number of MAF per Campaign of 14.0 Days	121.22	
Mean Number of Fatal Failures (Crashes) per Campaign of 14.0 Days	12.06	
Mean Number of Helicopters Lost to Enemy Action per Campaign of 14.0 Days	10.2	
Mean Repair and Turnaround Time per Entry into the Repair System	0.678439	0.005747
Mean Missions Started per campaign of 14.0 Days	137.56	
Prob of Returning to Base Safely given started a mission	0.91909	
Mean Time in High Threat Region per Helicopter per Campaign of 14.0Days	11.80142	
Mean Time in High Threat Region per Entry	1.363013	0.004639
Scheduled Time in High Threat Region	2.01686	
Mean Number of Times Individual Helicopters entered High Threat Region per Campaign of 14.0 Days	207.8	
Mean Survival Time of Individual Helicopters per Campaign of 14.0 Days	110.3635	1.851948
Mean Number of Helicopters in Repair System per hour per Campaign of 14.0 Days	2.322277	0.109045

Table 29. Data for Figure 12.

	Coverage					Helicopters				
	Percentiles							Percentiles		
Day	25%	50%	75%	se	Percent Coverage	Surviving Helos	se	25%	50%	75%
1	78.39%	83.27%	86.60%	0.53%	82.45%	21.87	0.12	21	22	23
2	85.20%	89.58%	91.70%	0.52%	88.89%	19.77	0.18	18	20	21
3	85.45%	88.90%	92.68%	0.50%	88.89%	17.51	0.23	16	17	19
4	84.58%	89.65%	93.40%	0.64%	88.87%	15.42	0.27	14	15	17
5	85.80%	89.81%	92.63%	0.59%	89.24%	13.11	0.29	11	13	15
6	81.93%	87.53%	92.32%	0.72%	86.87%	10.87	0.32	8.75	11	12.25
7	77.46%	87.21%	91.93%	1.48%	82.49%	8.79	0.34	6	9	11
8	65.53%	81.06%	88.29%	2.13%	73.38%	6.79	0.31	4.75	6	8
9	35.50%	59.20%	82.16%	2.98%	55.23%	5.45	0.26	3.75	5	7
10	10.24%	42.62%	61.63%	3.07%	40.44%	4.21	0.22	2.75	4	5
11	0.70%	30.99%	45.63%	2.75%	30.97%	3.5	0.16	2	3	4
12	0.00%	6.14%	36.60%	2.16%	17.48%	2.92	0.13	2	3	4
13	0.00%	0.00%	16.02%	1.71%	10.14%	2.65	0.11	2	3	3
14	0.00%	0.00%	0.00%	1.31%	5.96%	2.48	0.10	2	2	3

Total Runs	100	
Mean Number of MAF per Campaign of 14.0 Days	47.91	
Mean Number of Fatal Failures (Crashes) per Campaign of 14.0 Days	4.76	
Mean Number of Helicopters Lost to Enemy Action per Campaign of 14.0 Days	16.76	
Mean Repair and Turnaround Time per Entry into the Repair System	0.39834	0.003481
Mean Missions Started per campaign of 14.0 Days	156.63	
Prob of Returning to Base Safely given started a mission	0.931303	
Mean Time in High Threat Region per Helicopter per Campaign of 14.0Days	20.99556	
Mean Time in High Threat Region per Entry	1.742852	0.003101
Scheduled Time in High Threat Region	2.01686	
Mean Number of Times Individual Helicopters entered High Threat Region per Campaign of 14.0 Days	289.12	
Mean Survival Time of Individual Helicopters per Campaign of 14.0 Days	146.0683	1.985407
Mean Number of Helicopters in Repair System per hour per Campaign of 14.0 Days	0.714974	0.018502

Table 30. Data for Figure 14.

	Coverage					Helicopters				
	Percentiles							Percentiles		
Day	25%	50%	75%	se	Percent Coverage	Surviving Helos	se	25%	50%	75%
1	72.48%	76.59%	80.63%	0.60%	76.19%	21.39	0.16	20	21	23
2	76.71%	81.23%	86.23%	0.71%	81.32%	18.64	0.23	17	19	20
3	78.07%	82.68%	86.70%	0.67%	82.22%	15.66	0.30	14	16	18
4	77.78%	82.77%	87.21%	0.86%	81.66%	13.08	0.32	11	13	15
5	72.44%	80.54%	85.53%	1.16%	77.84%	10.31	0.35	7.75	11	13
6	64.38%	75.36%	81.85%	1.84%	69.67%	8.14	0.36	5	8	11
7	42.35%	66.58%	80.96%	2.43%	61.19%	6.12	0.32	4	5.5	8
8	30.27%	50.46%	70.34%	2.63%	48.75%	4.54	0.27	2.75	4	6
9	16.64%	34.54%	54.37%	2.59%	36.02%	3.36	0.21	2	3	4
10	0.68%	24.63%	37.12%	2.37%	25.58%	2.5	0.17	1	2	3
11	0.00%	6.24%	30.86%	2.03%	16.12%	1.92	0.13	1	2	2
12	0.00%	0.00%	21.60%	1.78%	11.23%	1.66	0.10	1	1	2
13	0.00%	0.00%	13.90%	1.60%	9.18%	1.41	0.08	1	1	2
14	0.00%	0.00%	0.00%	1.22%	5.96%	1.22	0.06	1	1	1

Total Runs	100	
Mean Number of MAF per Campaign of 14.0 Days	81.73	
Mean Number of Fatal Failures (Crashes) per Campaign of 14.0 Days	8.2	
Mean Number of Helicopters Lost to Enemy Action per Campaign of 14.0 Days	14.58	
Mean Repair and Turnaround Time per Entry into the Repair System	0.511008	0.004428
Mean Missions Started per campaign of 14.0 Days	151.77	
Prob of Returning to Base Safely given started a mission	0.924952	
Mean Time in High Threat Region per Helicopter per Campaign of 14.0Days	17.32763	
Mean Time in High Threat Region per Entry	1.593956	0.003789
Scheduled Time in High Threat Region	2.01686	
Mean Number of Times Individual Helicopters entered High Threat Region per Campaign of 14.0 Days	260.9	
Mean Survival Time of Individual Helicopters per Campaign of 14.0 Days	121.0823	1.772463
Mean Number of Helicopters in Repair System per hour per Campaign of 14.0 Days	1.077279	0.033694

Table 31. Data for Figure 15.

	Coverage					Helicopters				
	Percentiles							Percentiles		
Day	25%	50%	75%	se	Percent Coverage	Surviving Helos	se	25%	50%	75%
1	72.66%	76.36%	79.95%	0.63%	76.25%	21.46	0.16	21	22	23
2	76.65%	81.82%	85.74%	0.66%	80.99%	18.63	0.23	17	19	20
3	77.34%	81.23%	86.87%	0.66%	81.75%	16.21	0.28	14	16	18
4	77.59%	82.45%	86.12%	0.72%	81.71%	13.25	0.33	11	13	15.25
5	75.23%	81.03%	85.38%	1.04%	79.27%	10.67	0.35	8	11	13
6	64.48%	77.39%	82.44%	1.68%	72.07%	8.36	0.33	6	8	11
7	45.49%	68.89%	80.16%	2.29%	63.16%	6.53	0.31	4	6	8.25
8	30.57%	50.15%	72.14%	2.55%	49.25%	5.06	0.27	3	4	7
9	13.60%	33.41%	54.11%	2.59%	36.03%	3.96	0.23	2	3	5
10	0.00%	22.51%	37.39%	2.42%	24.84%	3.29	0.20	2	3	4
11	0.00%	2.38%	25.79%	2.00%	14.23%	2.69	0.16	2	2	3
12	0.00%	0.00%	12.88%	1.68%	9.70%	2.34	0.13	1	2	3
13	0.00%	0.00%	9.48%	1.35%	7.55%	2.09	0.11	1	2	3
14	0.00%	0.00%	7.87%	1.07%	5.94%	1.79	0.10	1	1	2.25

Total Runs	100	
Mean Number of MAF per Campaign of 14.0 Days	81.38	
Mean Number of Fatal Failures (Crashes) per Campaign of 14.0 Days	8.08	
Mean Number of Helicopters Lost to Enemy Action per Campaign of 14.0 Days	14.13	
Mean Repair and Turnaround Time per Entry into the Repair System	0.509968	0.004
Mean Missions Started per campaign of 14.0 Days	151.22	
Prob of Returning to Base Safely given started a mission	0.926564	
Mean Time in High Threat Region per Helicopter per Campaign of 14.0Days	17.33481	
Mean Time in High Threat Region per Entry	1.594861	0.004
Scheduled Time in High Threat Region	2.01686	
Mean Number of Times Individual Helicopters entered High Threat Region per Campaign of 14.0 Days	260.86	
Mean Survival Time of Individual Helicopters per Campaign of 14.0 Days	127.1746	1.901
Mean Number of Helicopters in Repair System per hour per Campaign of 14.0 Days	1.079734	0.038

Table 32. Data for Figure 16.

	Coverage					Helicopters				
	Percentiles							Percentiles		
Day	25%	50%	75%	se	Percent Coverage	Surviving Helos	se	25%	50%	75%
1	71.43%	77.62%	81.28%	0.69%	76.26%	21.61	0.15	21	22	23
2	76.10%	80.81%	84.38%	0.61%	80.43%	18.88	0.23	18	19	21
3	79.39%	82.31%	85.98%	0.59%	82.45%	16.18	0.27	15	16	18
4	77.88%	82.17%	87.14%	0.77%	81.74%	13.59	0.32	12	14	15.25
5	75.13%	81.72%	85.72%	1.18%	78.71%	11.24	0.34	9	11	14
6	69.68%	79.68%	85.74%	1.64%	75.32%	9.03	0.34	7	9	11
7	47.93%	69.15%	81.05%	2.15%	64.13%	6.91	0.32	4	7	9
8	33.65%	51.96%	73.17%	2.62%	50.40%	5.35	0.28	3	5	7
9	7.55%	34.33%	53.63%	2.63%	34.51%	4.23	0.23	3	4	5
10	0.00%	25.79%	40.54%	2.43%	26.56%	3.53	0.19	2	3	4.25
11	0.00%	13.78%	30.03%	2.02%	19.20%	2.76	0.15	2	2.5	4
12	0.00%	0.00%	25.19%	1.68%	12.97%	2.39	0.14	1	2	3
13	0.00%	0.00%	13.73%	1.55%	9.09%	2.1	0.12	1	2	3
14	0.00%	0.00%	14.64%	1.33%	8.76%	1.79	0.09	1	2	2

Total Runs	100	
Mean Number of MAF per Campaign of 14.0 Days	83.4	
Mean Number of Fatal Failures (Crashes) per Campaign of 14.0 Days	8.27	
Mean Number of Helicopters Lost to Enemy Action per Campaign of 14.0 Days	13.94	
Mean Repair and Turnaround Time per Entry into the Repair System	0.509845	0.004
Mean Missions Started per campaign of 14.0 Days	154.93	
Prob of Returning to Base Safely given started a mission	0.928322	
Mean Time in High Threat Region per Helicopter per Campaign of 14.0Days	17.75947	
Mean Time in High Threat Region per Entry	1.601756	0.004
Scheduled Time in High Threat Region	2.01686	
Mean Number of Times Individual Helicopters entered High Threat Region per Campaign of 14.0 Days	266.1	
Mean Survival Time of Individual Helicopters per Campaign of 14.0 Days	130.541	1.91
Mean Number of Helicopters in Repair System per hour per Campaign of 14.0 Days	1.098508	0.027

Table 33. Data for Figure 19.

	Coverage					Helicopters				
	Percentiles							Percentiles		
Day	25%	50%	75%	se	Percent Coverage	Surviving Helos	se	25%	50%	75%
1	71.34%	76.90%	80.91%	0.70%	76.03%	21.42	0.14	20	22	22
2	77.89%	81.94%	86.21%	0.64%	82.26%	18.69	0.22	17	19	20.25
3	77.71%	83.19%	87.40%	0.68%	82.29%	16.15	0.26	14	16	18
4	77.57%	82.21%	86.23%	0.74%	81.00%	13.72	0.29	12	14	16
5	77.66%	82.54%	87.08%	0.94%	80.91%	11.31	0.29	10	11	13.25
6	68.10%	78.67%	84.82%	1.35%	75.52%	9.15	0.30	7	10	11
7	56.90%	70.37%	81.02%	1.98%	66.41%	7.07	0.28	5	7	9
8	31.31%	51.81%	72.60%	2.64%	50.34%	5.21	0.25	3	5	7
9	3.84%	31.73%	50.37%	2.56%	31.11%	4.18	0.20	3	4	5
10	0.00%	16.13%	34.13%	2.28%	21.70%	3.41	0.16	2	3	4
11	0.00%	13.73%	28.78%	1.79%	17.43%	2.92	0.14	2	3	4
12	0.00%	2.02%	25.20%	1.77%	13.60%	2.53	0.11	2	3	3
13	0.00%	2.76%	20.02%	1.41%	10.95%	2.18	0.11	1	2	3
14	0.00%	2.86%	16.21%	1.51%	10.64%	1.81	0.10	1	2	2

Total Runs	100	
Mean Number of MAF per Campaign of 14.0 Days	83.17	
Mean Number of Fatal Failures (Crashes) per Campaign of 14.0 Days	8.3	
Mean Number of Helicopters Lost to Enemy Action per Campaign of 14.0 Days	13.89	
Mean Repair and Turnaround Time per Entry into the Repair System	0.509319	0.004
Mean Missions Started per campaign of 14.0 Days	154.84	
Prob of Returning to Base Safely given started a mission	0.928345	
Mean Time in High Threat Region per Helicopter per Campaign of 14.0Days	17.73118	
Mean Time in High Threat Region per Entry	1.610461	0.004
Scheduled Time in High Threat Region	2.01686	
Mean Number of Times Individual Helicopters entered High Threat Region per Campaign of 14.0 Days	264.24	
Mean Survival Time of Individual Helicopters per Campaign of 14.0 Days	130.4998	1.933
Mean Number of Helicopters in Repair System per hour per Campaign of 14.0 Days	1.110804	0.030

Table 34. Data for Figure 20.

	Coverage					Helicopters				
	Percentiles							Percentiles		
Day	25%	50%	75%	se	Percent Coverage	Surviving Helos	se	25%	50%	75%
1	73.58%	77.66%	81.73%	0.59%	77.67%	21.65	0.16	21	22	23
2	76.97%	82.93%	86.96%	0.72%	82.26%	19.02	0.22	17.75	19	20
3	77.46%	81.82%	88.22%	0.73%	82.00%	16.23	0.26	14	16	18
4	76.62%	82.02%	87.11%	0.71%	81.84%	13.49	0.34	11	13.5	16
5	75.62%	80.95%	86.63%	0.81%	80.57%	10.82	0.38	7.75	11	13
6	68.89%	79.71%	83.88%	1.87%	73.22%	8.41	0.37	6	8	11
7	48.26%	71.80%	82.02%	2.90%	61.40%	6.46	0.34	4	5	9
8	13.24%	46.43%	78.38%	3.31%	45.58%	5.26	0.31	3	4	8
9	0.00%	26.30%	65.03%	3.27%	32.52%	4.11	0.23	3	3	5
10	0.00%	8.64%	44.81%	2.88%	24.23%	3.41	0.18	2	3	4
11	0.00%	3.14%	26.62%	2.26%	16.01%	2.8	0.15	2	2.5	3
12	0.00%	0.00%	12.82%	1.78%	9.73%	2.5	0.14	2	2	3
13	0.00%	0.00%	0.00%	1.48%	5.72%	2.33	0.12	2	2	3
14	0.00%	0.00%	0.00%	1.20%	3.56%	2.24	0.11	2	2	3

Total Runs	100	
Mean Number of MAF per Campaign of 14.0 Days	80.74	
Mean Number of Fatal Failures (Crashes) per Campaign of 14.0 Days	8.02	
Mean Number of Helicopters Lost to Enemy Action per Campaign of 14.0 Days	13.74	
Mean Repair and Turnaround Time per Entry into the Repair System	0.513323	0.005
Mean Missions Started per campaign of 14.0 Days	148.63	
Prob of Returning to Base Safely given started a mission	0.926798	
Mean Time in High Threat Region per Helicopter per Campaign of 14.0Days	17.13487	
Mean Time in High Threat Region per Entry	1.605892	0.004
Scheduled Time in High Threat Region	2.01686	
Mean Number of Times Individual Helicopters entered High Threat Region per Campaign of 14.0 Days	256.08	
Mean Survival Time of Individual Helicopters per Campaign of 14.0 Days	129.3895	1.924
Mean Number of Helicopters in Repair System per hour per Campaign of 14.0 Days	0.486483	0.013

Table 35. Data for Figure 22.

	Coverage					Helicopters				
	Percentiles							Percentiles		
Day	25%	50%	75%	se	Percent Coverage	Surviving Helos	se	25%	50%	75%
1	72.38%	77.14%	81.40%	0.61%	76.71%	21.28	0.16	21	21.5	22
2	77.20%	82.20%	86.69%	0.74%	81.72%	18.71	0.22	17	19	20
3	77.09%	81.36%	86.54%	0.63%	81.78%	16.2	0.27	15	16	18
4	75.70%	80.79%	85.56%	0.70%	81.06%	13.52	0.31	11	14	16
5	75.99%	82.03%	86.37%	1.06%	80.23%	11.04	0.34	9	11	13
6	74.65%	78.65%	83.60%	1.72%	74.50%	8.39	0.31	6	9	10.25
7	53.17%	76.68%	82.33%	2.62%	65.61%	6.37	0.32	4	6	8
8	23.83%	52.20%	75.72%	3.11%	48.23%	4.62	0.25	3	4	6
9	0.00%	25.05%	47.15%	2.83%	29.70%	3.68	0.22	2	3	5
10	0.00%	6.87%	27.50%	2.47%	18.77%	2.98	0.17	2	3	4
11	0.00%	0.05%	23.09%	2.07%	14.24%	2.55	0.13	2	2	3
12	0.00%	0.00%	10.93%	1.59%	8.64%	2.28	0.11	1	2	3
13	0.00%	0.00%	0.00%	1.06%	3.29%	2.12	0.11	1	2	3
14	0.00%	0.00%	0.00%	0.46%	1.10%	2.06	0.11	1	2	3

Total Runs	100	
Mean Number of MAF per Campaign of 14.0 Days	79.26	
Mean Number of Fatal Failures (Crashes) per Campaign of 14.0 Days	7.89	
Mean Number of Helicopters Lost to Enemy Action per Campaign of 14.0 Days	14.05	
Mean Repair and Turnaround Time per Entry into the Repair System	0.509588	0.004
Mean Missions Started per campaign of 14.0 Days	147.76	
Prob of Returning to Base Safely given started a mission	0.925758	
Mean Time in High Threat Region per Helicopter per Campaign of 14.0Days	16.88499	
Mean Time in High Threat Region per Entry	1.597319	0.004
Scheduled Time in High Threat Region	2.01686	
Mean Number of Times Individual Helicopters entered High Threat Region per Campaign of 14.0 Days	253.7	
Mean Survival Time of Individual Helicopters per Campaign of 14.0 Days	126.432	1.882
Mean Number of Helicopters in Repair System per hour per Campaign of 14.0 Days	0.416127	0.008

Table 36. Data for Figure 23.

	Coverage					Helicopters				
	Percentiles							Percentiles		
Day	25%	50%	75%	se	Percent Coverage	Surviving Helos	se	25%	50%	75%
1	72.56%	76.47%	80.01%	0.59%	75.86%	21.51	0.15	20	22	23
2	77.01%	81.18%	87.07%	0.77%	81.48%	18.81	0.19	18	19	20
3	78.55%	82.01%	86.77%	0.69%	82.19%	16.21	0.24	14	16	18
4	78.78%	82.72%	87.14%	0.61%	82.52%	13.58	0.29	11	13.5	16
5	75.87%	81.18%	85.18%	0.81%	80.25%	10.82	0.33	8.75	11	13.25
6	75.33%	81.11%	85.80%	1.63%	76.76%	8.42	0.33	6	8	11
7	55.03%	71.47%	81.99%	2.45%	65.51%	6.22	0.29	4	6	8
8	28.24%	48.07%	71.18%	2.73%	47.68%	4.79	0.25	3	4	6
9	0.00%	27.88%	47.91%	2.79%	30.52%	3.88	0.20	3	3	5
10	0.00%	14.37%	41.76%	2.36%	21.74%	3.22	0.15	2	3	4
11	0.00%	10.98%	28.57%	1.78%	16.07%	2.65	0.13	2	3	3
12	0.00%	0.00%	20.60%	1.66%	11.19%	2.25	0.10	2	2	3
13	0.00%	0.00%	18.02%	1.35%	9.96%	1.95	0.08	1	2	2
14	0.00%	0.00%	9.14%	1.16%	6.61%	1.71	0.07	1	2	2

Total Runs	100	
Mean Number of MAF per Campaign of 14.0 Days	81.1	
Mean Number of Fatal Failures (Crashes) per Campaign of 14.0 Days	8.02	
Mean Number of Helicopters Lost to Enemy Action per Campaign of 14.0 Days	14.27	
Mean Repair and Turnaround Time per Entry into the Repair System	0.508082	0.004
Mean Missions Started per campaign of 14.0 Days	152.05	
Prob of Returning to Base Safely given started a mission	0.926702	
Mean Time in High Threat Region per Helicopter per Campaign of 14.0Days	17.45606	
Mean Time in High Threat Region per Entry	1.599456	0.004
Scheduled Time in High Threat Region	2.01686	
Mean Number of Times Individual Helicopters entered High Threat Region per Campaign of 14.0 Days	261.93	
Mean Survival Time of Individual Helicopters per Campaign of 14.0 Days	127.0269	1.876
Mean Number of Helicopters in Repair System per hour per Campaign of 14.0 Days	0.491271	0.011

Table 37. Data for Figure 24.

	Coverage					Helicopters				
	Percentiles							Percentiles		
Day	25%	50%	75%	se	Percent Coverage	Surviving Helos	se	25%	50%	75%
1	72.73%	76.49%	80.36%	0.58%	76.49%	21.41	0.17	20	22	23
2	76.39%	80.97%	85.53%	0.67%	81.20%	18.78	0.22	17	19	20
3	77.54%	81.89%	86.63%	0.62%	82.01%	15.99	0.29	14	16	18
4	76.36%	83.29%	87.98%	0.75%	82.19%	13.4	0.32	11	13.5	16
5	76.43%	81.60%	87.06%	1.05%	80.75%	11.03	0.34	8	11	13.25
6	73.21%	79.85%	84.24%	1.33%	77.17%	8.55	0.34	6	8	11
7	54.30%	74.18%	83.22%	2.30%	65.38%	6.45	0.31	4	6	9
8	30.72%	54.23%	78.78%	3.01%	50.70%	5.08	0.26	3	4	7
9	0.00%	30.75%	55.42%	3.05%	33.44%	4.02	0.21	3	4	5
10	0.00%	15.79%	40.66%	2.59%	23.49%	3.26	0.16	2	3	4
11	0.00%	10.46%	27.46%	1.81%	15.38%	2.7	0.12	2	3	3.25
12	0.00%	0.00%	19.18%	1.56%	10.41%	2.38	0.11	2	2	3
13	0.00%	0.00%	16.14%	1.37%	8.97%	2.08	0.10	1	2	3
14	0.00%	0.00%	7.17%	1.25%	6.56%	1.91	0.09	1	2	2

Total Runs	100	
Mean Number of MAF per Campaign of 14.0 Days	82.96	
Mean Number of Fatal Failures (Crashes) per Campaign of 14.0 Days	8.2	
Mean Number of Helicopters Lost to Enemy Action per Campaign of 14.0 Days	13.89	
Mean Repair and Turnaround Time per Entry into the Repair System	0.510884	0.004
Mean Missions Started per campaign of 14.0 Days	153.39	
Prob of Returning to Base Safely given started a mission	0.927994	
Mean Time in High Threat Region per Helicopter per Campaign of 14.0Days	17.60338	
Mean Time in High Threat Region per Entry	1.601278	0.004
Scheduled Time in High Threat Region	2.01686	
Mean Number of Times Individual Helicopters entered High Threat Region per Campaign of 14.0 Days	263.84	
Mean Survival Time of Individual Helicopters per Campaign of 14.0 Days	127.6001	1.906
Mean Number of Helicopters in Repair System per hour per Campaign of 14.0 Days	0.51488	0.011

Table 38. Data for Figure 25.

APPENDIX C: SIMULATION DATA OUTPUT FOR NON-HOMOGENEOUS FAILURE RATE PROCESS

The following tables list extended output results from each of the simulations conducted for this thesis: They summarize measures of variability between hypothetical campaigns (100 campaigns/replications).

	Coverage					Helicopters				
	Percentiles							Percentiles		
Day	25%	50%	75%	se	Percent Coverage	Surviving Helos	se	25%	50%	75%
1	74.57%	79.58%	82.59%	0.66%	78.30%	22.49	0.14	22	23	23
2	81.00%	85.00%	88.61%	0.66%	84.47%	21.11	0.19	20	21	22
3	79.75%	84.45%	88.15%	0.62%	83.61%	19.72	0.23	19	20	22
4	80.23%	85.21%	89.54%	0.66%	84.53%	18.31	0.26	17	18.5	20
5	79.30%	83.59%	88.17%	0.68%	83.11%	16.89	0.27	15	17	19
6	78.30%	82.66%	87.81%	0.72%	82.99%	15.44	0.29	14	15	18
7	78.29%	82.50%	87.99%	0.74%	82.62%	14.09	0.31	12	14	16.25
8	77.35%	83.72%	87.52%	1.05%	80.89%	12.7	0.33	10.75	13	15.25
9	74.99%	82.98%	87.00%	1.27%	79.48%	11.33	0.33	9	11	14
10	68.50%	79.83%	87.05%	1.65%	75.95%	10.05	0.32	8	10	12.25
11	64.70%	73.88%	80.79%	1.76%	70.46%	9.03	0.33	7	9	11
12	53.62%	73.13%	81.83%	2.35%	66.28%	8.08	0.32	6	8	10
13	41.99%	61.48%	79.10%	2.49%	57.60%	7.04	0.31	5	7	9
14	32.84%	48.11%	70.47%	2.73%	47.69%	6.21	0.28	4	6	8
15	16.55%	37.63%	59.82%	2.82%	38.79%	5.58	0.26	4	5	7
16	0.00%	27.47%	42.45%	2.49%	28.14%	5.1	0.23	3	4.5	6
17	0.00%	29.20%	43.30%	2.52%	27.03%	4.77	0.21	3	4	6
18	0.00%	22.57%	38.31%	2.24%	24.53%	4.37	0.20	3	4	6
19	0.00%	18.19%	36.55%	2.06%	20.67%	3.96	0.17	3	4	5
20	0.00%	0.00%	33.82%	1.94%	15.02%	3.73	0.17	3	3	5
21	0.00%	0.00%	24.36%	1.79%	11.70%	3.57	0.16	3	3	4

Total Runs	100	
Mean Number of MAF per Campaign of 21.0 Days	144.12	
Mean Number of Fatal Failures (Crashes) per Campaign of 21.0 Days	14.34	
Mean Number of Helicopters Lost to Enemy Action per Campaign of 21.0 Days	6.09	
Mean Repair and Turnaround Time per Entry into the Repair System	0.512936	0.003354
Mean Missions Started per campaign of 21.0 Days	258.6	
Prob of Returning to Base Safely given started a mission	0.960499	
Mean Time in High Threat Region per Helicopter per Campaign of 21.0Days	30.95233	
Mean Time in High Threat Region per Entry	1.651085	0.002744
Scheduled Time in High Threat Region	2.01686	
Mean Number of Times Individual Helicopters entered High Threat Region per Campaign of 21.0 Days	449.92	
Mean Survival Time of Individual Helicopters per Campaign of 21.0 Days	233.5836	3.25317
Mean Number of Helicopters in Repair System per hour per Campaign of 21.0 Days	1.329924	0.035045

Table 39. Data for Figure 26.

	Coverage					Helicopters				
	Percentiles							Percentiles		
Day	25%	50%	75%	se	Percent Coverage	Surviving Helos	se	25%	50%	75%
1	74.91%	78.29%	82.41%	0.63%	78.37%	22.51	0.14	22	23	24
2	78.34%	84.61%	88.17%	0.66%	83.85%	20.64	0.22	19.75	21	22
3	79.71%	83.37%	87.96%	0.62%	83.30%	18.72	0.27	17	19	20.25
4	78.35%	83.21%	86.73%	0.65%	82.36%	16.84	0.32	15	17	19
5	77.50%	82.28%	87.36%	0.71%	82.73%	14.87	0.34	13	16	17
6	75.28%	80.35%	86.50%	1.04%	79.59%	13.14	0.37	11	14	15
7	73.69%	81.09%	85.65%	1.39%	78.26%	11.5	0.40	9	12	14
8	68.67%	77.18%	85.72%	2.02%	72.39%	10.03	0.39	7	10	13
9	57.59%	77.50%	84.18%	2.26%	68.36%	8.57	0.37	6	8.5	11
10	46.10%	69.65%	80.23%	2.55%	60.81%	7.37	0.35	5	7	9.25
11	32.75%	53.21%	75.88%	2.82%	51.55%	6.16	0.32	4	6	8
12	21.75%	39.95%	71.92%	2.97%	44.53%	5.16	0.29	3	4	7
13	0.00%	29.52%	52.93%	2.92%	32.53%	4.44	0.25	3	4	6
14	0.00%	21.16%	43.17%	2.66%	25.33%	4	0.23	2	4	5
15	0.00%	0.00%	34.23%	2.54%	18.90%	3.66	0.19	2	3	4.25
16	0.00%	0.00%	28.41%	2.12%	15.17%	3.38	0.18	2	3	4
17	0.00%	0.00%	24.55%	1.77%	12.88%	3.12	0.16	2	3	4
18	0.00%	12.75%	25.75%	1.65%	14.68%	2.88	0.15	2	3	4
19	0.00%	0.00%	26.16%	1.60%	11.70%	2.62	0.14	1	2	3.25
20	0.00%	0.00%	10.86%	1.40%	7.51%	2.48	0.13	1	2	3
21	0.00%	0.00%	0.00%	1.00%	4.26%	2.37	0.13	1	2	3

Total Runs	100	
Mean Number of MAF per Campaign of 21.0 Days	118.94	
Mean Number of Fatal Failures (Crashes) per Campaign of 21.0 Days	11.7	
Mean Number of Helicopters Lost to Enemy Action per Campaign of 21.0 Days	9.93	
Mean Repair and Turnaround Time per Entry into the Repair System	0.51207	0.003693
Mean Missions Started per campaign of 21.0 Days	216.25	
Prob of Returning to Base Safely given started a mission	0.949988	
Mean Time in High Threat Region per Helicopter per Campaign of 21.0Days	25.55777	
Mean Time in High Threat Region per Entry	1.633693	0.003041
Scheduled Time in High Threat Region	2.01686	
Mean Number of Times Individual Helicopters entered High Threat Region per Campaign of 21.0 Days	375.46	
Mean Survival Time of Individual Helicopters per Campaign of 21.0 Days	195.1438	2.969122
Mean Number of Helicopters in Repair System per hour per Campaign of 21.0 Days	1.068534	0.034144

Table 40. Data for Figure 27.

	Coverage					Helicopters				
	Percentiles							Percentiles		
Day	25%	50%	75%	se	Percent Coverage	Surviving Helos	se	25%	50%	75%
1	72.61%	77.36%	81.97%	0.62%	76.93%	21.55	0.16	20	22	23
2	77.32%	81.43%	86.80%	0.69%	81.82%	18.78	0.22	17	19	21
3	76.46%	80.82%	85.83%	0.69%	80.72%	16.01	0.27	14	16	18
4	77.06%	81.60%	86.14%	0.70%	81.90%	13.35	0.30	11	13	15
5	74.44%	80.87%	85.48%	1.04%	78.98%	10.83	0.31	9	11	12.25
6	70.08%	77.57%	84.78%	1.33%	75.47%	8.48	0.30	6	8	11
7	53.50%	68.55%	78.93%	2.09%	64.12%	6.49	0.29	4	6	8.25
8	22.58%	49.66%	68.11%	2.77%	45.46%	5.07	0.23	3	5	7
9	5.15%	34.02%	50.76%	2.63%	33.22%	4.18	0.20	3	4	5
10	0.00%	26.02%	41.20%	2.37%	25.90%	3.47	0.17	2	3	5
11	0.00%	13.73%	34.33%	1.93%	18.83%	2.83	0.13	2	3	4
12	0.00%	0.00%	24.10%	1.66%	11.57%	2.46	0.11	2	2	3
13	0.00%	0.00%	6.24%	1.25%	5.98%	2.26	0.11	2	2	3
14	0.00%	0.00%	0.00%	0.66%	2.29%	2.17	0.11	1	2	3
15	0.00%	0.00%	0.00%	0.63%	1.98%	2.11	0.10	1	2	3
16	0.00%	0.00%	0.00%	0.61%	1.87%	2.07	0.10	1	2	2.25
17	0.00%	0.00%	0.90%	0.90%	4.12%	1.94	0.10	1	2	2
18	0.00%	0.00%	7.52%	1.02%	5.51%	1.73	0.09	1	1	2
19	0.00%	0.00%	0.00%	1.10%	4.56%	1.64	0.09	1	1	2
20	0.00%	0.00%	0.00%	0.97%	3.72%	1.55	0.09	1	1	2
21	0.00%	0.00%	0.00%	0.83%	3.04%	1.46	0.09	1	1	2

Total Runs	100	
Mean Number of MAF per Campaign of 21.0 Days	83.12	
Mean Number of Fatal Failures (Crashes) per Campaign of 21.0 Days	8.32	
Mean Number of Helicopters Lost to Enemy Action per Campaign of 21.0 Days	14.22	
Mean Repair and Turnaround Time per Entry into the Repair System	0.506872	0.004373
Mean Missions Started per campaign of 21.0 Days	155.67	
Prob of Returning to Base Safely given started a mission	0.927603	
Mean Time in High Threat Region per Helicopter per Campaign of 21.0Days	17.95225	
Mean Time in High Threat Region per Entry	1.602641	0.003705
Scheduled Time in High Threat Region	2.01686	
Mean Number of Times Individual Helicopters entered High Threat Region per Campaign of 21.0 Days	268.84	
Mean Survival Time of Individual Helicopters per Campaign of 21.0 Days	141.4759	2.589713
Mean Number of Helicopters in Repair System per hour per Campaign of 21.0 Days	0.734868	0.019681

Table 41. Data for Figure 28.

	Coverage					Helicopters				
	Percentiles							Percentiles		
Day	25%	50%	75%	se	Percent Coverage	Surviving Helos	se	25%	50%	75%
1	73.17%	76.84%	81.77%	0.67%	77.05%	21.4	0.17	20.75	22	23
2	78.68%	82.56%	86.07%	0.69%	81.78%	18.73	0.25	17	19	21
3	78.33%	80.96%	85.63%	0.69%	81.77%	15.7	0.32	14	16	18
4	76.21%	81.39%	86.38%	0.78%	80.79%	13.14	0.37	11	13	16
5	73.64%	78.89%	86.38%	1.26%	77.50%	10.79	0.42	8	11	14
6	63.92%	77.97%	84.51%	2.10%	70.76%	8.55	0.39	5	9	12
7	47.30%	67.79%	80.75%	2.81%	60.26%	6.84	0.36	4	7	9
8	6.87%	55.46%	73.21%	3.22%	46.29%	5.33	0.31	3	5	7
9	0.00%	34.51%	57.71%	3.03%	33.24%	4.28	0.25	2	4	6
10	0.00%	10.13%	41.24%	2.69%	23.48%	3.51	0.20	2	3	4.25
11	0.00%	15.14%	34.38%	2.01%	18.54%	2.89	0.17	2	3	4
12	0.00%	0.00%	19.17%	1.77%	11.22%	2.55	0.14	1	2	3
13	0.00%	0.00%	0.00%	1.22%	5.49%	2.33	0.12	1	2	3
14	0.00%	0.00%	0.00%	0.98%	3.05%	2.23	0.11	1	2	3

Total Runs	100	
Mean Number of MAF per Campaign of 14:0 Days	78.07	
Mean Number of Fatal Failures (Crashes) per Campaign of 14.0 Days	7.82	
Mean Number of Helicopters Lost to Enemy Action per Campaign of 14.0 Days	13.95	
Mean Repair and Turnaround Time per Entry into the Repair System	0.505559	0.00445
Mean Missions Started per campaign of 14.0 Days	147.2	
Prob of Returning to Base Safely given started a mission	0.926053	
Mean Time in High Threat Region per Helicopter per Campaign of 14.0Days	17.0081	
Mean Time in High Threat Region per Entry	1.607571	0.003777
Scheduled Time in High Threat Region	2.01686	
Mean Number of Times Individual Helicopters entered High Threat Region per Campaign of 14.0 Days	253.92	
Mean Survival Time of Individual Helicopters per Campaign of 14.0 Days	129.0415	1.956605
Mean Number of Helicopters in Repair System per hour per Campaign of 14.0 Days	1.052113	0.037308

Table 42. Data for Figure 29, Figure 33, Figure 40, Figure 41, and Figure 44.

	Coverage					Helicopters				
	Percentiles							Percentiles		
Day	25%	50%	75%	se	Percent Coverage	Surviving Helos	se	25%	50%	75%
1	73.19%	76.79%	81.26%	0.64%	77.05%	21.39	0.15	20	22	22
2	77.55%	82.97%	86.75%	0.67%	82.15%	18.96	0.22	18	19	21
3	76.60%	81.86%	86.39%	0.72%	81.85%	16.21	0.26	15	16	18
4	76.44%	82.22%	85.62%	0.74%	81.14%	13.38	0.29	11	13	16
5	73.38%	80.00%	85.97%	0.99%	78.84%	10.88	0.35	9	11	13
6	67.39%	78.46%	84.28%	1.63%	74.02%	8.55	0.34	6	9	11
7	56.35%	70.31%	80.20%	2.29%	63.63%	6.39	0.31	4	6	8.25
8	33.58%	49.22%	74.11%	2.81%	49.23%	4.75	0.26	3	4	6.25
9	3.56%	30.24%	57.38%	2.70%	32.81%	3.64	0.20	2	3	5
10	0.00%	13.73%	34.78%	2.35%	21.26%	2.99	0.16	2	3	4
11	0.00%	7.86%	34.38%	2.06%	17.45%	2.61	0.13	2	2	3
12	0.00%	2.05%	16.91%	1.73%	11.75%	2.05	0.11	1	2	3
13	0.00%	0.00%	6.87%	1.41%	6.77%	1.82	0.09	1	2	2
14	0.00%	0.00%	0.00%	1.05%	4.18%	1.7	0.08	1	2	2

Total Runs	100	
Mean Number of MAF per Campaign of 14.0 Days	79.86	
Mean Number of Fatal Failures (Crashes) per Campaign of 14.0 Days	7.96	
Mean Number of Helicopters Lost to Enemy Action per Campaign of 14.0 Days	14.34	
Mean Repair and Turnaround Time per Entry into the Repair System	0.507085	0.004426
Mean Missions Started per campaign of 14.0 Days	150.3	
Prob of Returning to Base Safely given started a mission	0.925815	
Mean Time in High Threat Region per Helicopter per Campaign of 14.0Days	17.31263	
Mean Time in High Threat Region per Entry	1.594655	0.003804
Scheduled Time in High Threat Region	2.01686	
Mean Number of Times Individual Helicopters entered High Threat Region per Campaign of 14.0 Days	260.56	
Mean Survival Time of Individual Helicopters per Campaign of 14.0 Days	126.1536	1.84997
Mean Number of Helicopters in Repair System per hour per Campaign of 14.0 Days	1.062289	0.035139

Table 43. Data for Figure 30.

	Coverage					Helicopters				
	Percentiles							Percentiles		
Day	25%	50%	75%	se	Percent Coverage	Surviving Helos	se	25%	50%	75%
1	73.22%	77.20%	81.01%	0.62%	77.33%	21.51	0.16	20	22	23
2	77.32%	81.60%	86.54%	0.76%	81.90%	19.1	0.22	17.75	19	21
3	77.67%	82.32%	87.33%	0.73%	82.16%	16.53	0.23	15	17	18
4	77.86%	82.38%	86.24%	0.69%	82.22%	13.9	0.27	12	14	15
5	77.29%	82.66%	86.51%	0.77%	81.29%	11.28	0.28	10	11	13
6	71.50%	79.40%	84.36%	1.32%	76.69%	8.74	0.28	7	9	11
7	60.84%	74.88%	82.09%	1.90%	68.87%	6.61	0.27	5	7	9
8	33.37%	55.33%	73.95%	2.52%	51.98%	4.7	0.24	3	4	6
9	8.82%	36.27%	56.59%	2.90%	37.22%	3.55	0.18	2	3	5
10	0.00%	13.69%	41.93%	2.65%	23.21%	2.87	0.15	2	3	3
11	0.00%	0.00%	28.52%	2.12%	14.81%	2.38	0.11	2	2	3
12	0.00%	0.00%	21.27%	1.46%	10.79%	2.02	0.10	1	2	3
13	0.00%	0.00%	12.19%	1.54%	8.45%	1.76	0.09	1	2	2
14	0.00%	0.00%	0.00%	1.05%	4.43%	1.59	0.07	1	1	2

Total Runs	100	
Mean Number of MAF per Campaign of 14.0 Days	82.21	
Mean Number of Fatal Failures (Crashes) per Campaign of 14.0 Days	8.18	
Mean Number of Helicopters Lost to Enemy Action per Campaign of 14.0 Days	14.23	
Mean Repair and Turnaround Time per Entry into the Repair System	0.50807	0.00438
Mean Missions Started per campaign of 14.0 Days	154.04	
Prob of Returning to Base Safely given started a mission	0.927259	
Mean Time in High Threat Region per Helicopter per Campaign of 14.0Days	17.7887	
Mean Time in High Threat Region per Entry	1.603188	0.003694
Scheduled Time in High Threat Region	2.01686	
Mean Number of Times Individual Helicopters entered High Threat Region per Campaign of 14.0 Days	266.3	
Mean Survival Time of Individual Helicopters per Campaign of 14.0 Days	127.4619	1.824358
Mean Number of Helicopters in Repair System per hour per Campaign of 14.0 Days	1.113123	0.028968

Table 44. Data for Figure 31.

	Coverage					Helicopters				
	Percentiles							Percentiles		
Day	25%	50%	75%	se	Percent Coverage	Surviving Helos	se	25%	50%	75%
1	75.65%	79.73%	83.60%	0.60%	79.54%	21.53	0.16	21	22	23
2	79.42%	82.55%	87.60%	0.66%	82.83%	19.14	0.23	18	19	21
3	77.28%	82.17%	87.08%	0.68%	81.70%	16.53	0.26	15	17	19
4	77.59%	82.22%	88.20%	0.72%	82.77%	14.18	0.28	12.75	14	16
5	75.60%	80.80%	85.65%	0.84%	80.71%	11.55	0.31	9.75	11.5	14
6	73.01%	81.37%	85.64%	1.28%	77.90%	9.04	0.31	7	9	11
7	58.09%	72.08%	80.15%	1.84%	67.36%	6.74	0.28	5	7	8
8	36.77%	51.78%	68.73%	2.31%	50.98%	4.98	0.26	3	5	7
9	11.71%	37.26%	53.34%	2.42%	34.85%	3.81	0.22	2	3.5	5
10	0.00%	18.30%	35.67%	2.28%	21.82%	3.13	0.20	2	3	4
11	0.00%	7.61%	28.82%	2.12%	16.93%	2.6	0.14	2	2	3
12	0.00%	0.00%	21.22%	1.68%	10.98%	2.22	0.10	2	2	3
13	0.00%	0.00%	6.87%	1.16%	6.08%	1.99	0.09	1	2	3
14	0.00%	0.00%	0.00%	0.90%	3.03%	1.91	0.09	1	2	2

Total Runs	100	
Mean Number of MAF per Campaign of 14.0 Days	78.28	
Mean Number of Fatal Failures (Crashes) per Campaign of 14.0 Days	7.67	
Mean Number of Helicopters Lost to Enemy Action per Campaign of 14.0 Days	14.42	
Mean Repair and Turnaround Time per Entry into the Repair System	0.499622	0.004377
Mean Missions Started per campaign of 14.0 Days	151.43	
Prob of Returning to Base Safely given started a mission	0.927062	
Mean Time in High Threat Region per Helicopter per Campaign of 14.0Days	17.66401	
Mean Time in High Threat Region per Entry	1.61119	0.00375
Scheduled Time in High Threat Region	2.01686	
Mean Number of Times Individual Helicopters entered High Threat Region per Campaign of 14.0 Days	263.12	
Mean Survival Time of Individual Helicopters per Campaign of 14.0 Days	130.1922	1.862963
Mean Number of Helicopters in Repair System per hour per Campaign of 14.0 Days	1.043132	0.03002

Table 45. Data for Figure 32.

	Coverage					Helicopters				
	Percentiles							Percentiles		
Day	25%	50%	75%	se	Percent Coverage	Surviving Helos	se	25%	50%	75%
1	74.21%	76.94%	81.00%	0.53%	77.67%	21.63	0.16	20.75	22	23
2	79.10%	83.37%	86.12%	0.69%	82.94%	18.92	0.24	17	19	21
3	77.74%	81.28%	84.69%	0.69%	80.95%	16.24	0.31	14	16	19
4	75.58%	81.85%	86.02%	0.74%	80.82%	13.59	0.37	11	13	17
5	74.70%	80.03%	84.69%	0.89%	78.22%	11.17	0.38	8	11	14
6	66.31%	77.88%	83.52%	1.67%	72.38%	8.75	0.38	6	8.5	11.25
7	44.88%	68.65%	80.03%	2.38%	62.10%	6.95	0.35	4.75	6	9
8	28.09%	48.96%	70.21%	2.77%	47.50%	5.58	0.30	3.75	5	7
9	4.89%	34.75%	63.21%	2.87%	34.63%	4.57	0.26	3	4	6
10	0.00%	21.16%	40.56%	2.66%	25.50%	3.9	0.23	2	4	4.25
11	0.00%	13.73%	34.17%	2.35%	20.74%	3.18	0.18	2	3	4
12	0.00%	0.00%	19.46%	1.97%	12.59%	2.79	0.15	2	3	3
13	0.00%	0.00%	0.00%	1.48%	6.56%	2.57	0.14	2	2	3
14	0.00%	0.00%	0.00%	1.17%	4.01%	2.46	0.13	2	2	3

Total Runs	100	
Mean Number of MAF per Campaign of 14.0 Days	80.52	
Mean Number of Fatal Failures (Crashes) per Campaign of 14.0 Days	8.03	
Mean Number of Helicopters Lost to Enemy Action per Campaign of 14.0 Days	13.51	
Mean Repair and Turnaround Time per Entry into the Repair System	0.507964	0.004445
Mean Missions Started per campaign of 14.0 Days	150.68	
Prob of Returning to Base Safely given started a mission	0.928524	
Mean Time in High Threat Region per Helicopter per Campaign of 14.0Days	17.4107	
Mean Time in High Threat Region per Entry	1.605289	0.003744
Scheduled Time in High Threat Region	2.01686	
Mean Number of Times Individual Helicopters entered High Threat Region per Campaign of 14.0 Days	260.3	
Mean Survival Time of Individual Helicopters per Campaign of 14.0 Days	132.8203	1.990931
Mean Number of Helicopters in Repair System per hour per Campaign of 14.0 Days	1.092635	0.03709

Table 46. Data for Figure 34.

	Coverage					Helicopters				
	Percentiles							Percentiles		
Day	25%	50%	75%	se	Percent Coverage	Surviving Helos	se	25%	50%	75%
1	67.03%	71.09%	75.25%	0.64%	70.74%	20.93	0.18	20	21	22
2	68.02%	72.27%	76.39%	0.63%	71.77%	17.5	0.25	16	18	19.25
3	66.48%	71.33%	76.07%	0.75%	71.15%	14.23	0.31	12	15	16
4	59.35%	67.40%	76.69%	1.33%	66.43%	11.25	0.33	9	11	13.25
5	44.75%	62.08%	70.77%	1.66%	57.01%	8.66	0.32	6.75	9	11
6	31.63%	43.81%	62.06%	1.98%	46.06%	6.48	0.30	4	7	9
7	25.44%	35.61%	47.97%	1.86%	35.04%	4.57	0.25	3	4	6
8	7.60%	23.97%	35.46%	1.74%	23.23%	3.37	0.20	2	3	4
9	0.00%	8.42%	22.32%	1.64%	14.07%	2.59	0.17	2	2	3
10	0.00%	0.00%	12.46%	1.22%	7.94%	2.16	0.14	1	2	2
11	0.00%	0.00%	13.28%	1.28%	7.60%	1.9	0.11	1	2	2
12	0.00%	0.00%	6.87%	1.01%	5.35%	1.62	0.09	1	1	2
13	0.00%	0.00%	0.00%	0.97%	4.35%	1.46	0.07	1	1	2
14	0.00%	0.00%	0.00%	0.71%	2.29%	1.33	0.06	1	1	2

Total Runs	100	
Mean Number of MAF per Campaign of 14.0 Days	118.18	
Mean Number of Fatal Failures (Crashes) per Campaign of 14.0 Days	11.67	
Mean Number of Helicopters Lost to Enemy Action per Campaign of 14.0 Days	11	
Mean Repair and Turnaround Time per Entry into the Repair System	0.656172	0.006
Mean Missions Started per campaign of 14.0 Days	141.33	
Prob of Returning to Base Safely given started a mission	0.919798	
Mean Time in High Threat Region per Helicopter per Campaign of 14.0Days	12.63148	
Mean Time in High Threat Region per Entry	1.390877	0.005
Scheduled Time in High Threat Region	2.01686	
Mean Number of Times Individual Helicopters entered High Threat Region per Campaign of 14.0 Days	217.96	
Mean Survival Time of Individual Helicopters per Campaign of 14.0 Days	109.0396	1.741
Mean Number of Helicopters in Repair System per hour per Campaign of 14.0 Days	2.046475	0.084

Table 47. Data for Figure 35.

	Coverage					Helicopters				
	Percentiles							Percentiles		
Day	25%	50%	75%	se	Percent Coverage	Surviving Helos	se	25%	50%	75%
1	76.57%	79.92%	82.58%	0.55%	79.75%	21.45	0.16	21	22	23
2	78.38%	82.56%	88.19%	0.68%	82.66%	18.85	0.22	18	19	20
3	78.16%	82.54%	87.33%	0.68%	82.89%	16.14	0.25	15	16	18
4	76.85%	82.07%	85.79%	0.69%	81.67%	13.51	0.30	11	14	16
5	77.87%	81.01%	87.30%	1.02%	81.00%	11.07	0.33	9	11	14
6	70.17%	77.79%	84.80%	1.33%	75.29%	8.64	0.35	6	9	11
7	48.51%	68.84%	79.30%	2.08%	63.05%	6.75	0.33	4	7	9.25
8	27.57%	53.51%	73.47%	2.81%	48.84%	5.18	0.28	3	5	7
9	3.45%	34.84%	53.42%	2.76%	34.72%	4.03	0.24	2	3.5	5
10	0.00%	27.07%	43.03%	2.48%	26.57%	3.32	0.19	2	3	4.25
11	0.00%	17.36%	36.85%	2.12%	20.38%	2.74	0.14	2	3	4
12	0.00%	1.83%	26.36%	1.83%	13.90%	2.2	0.11	1	2	3
13	0.00%	0.00%	9.49%	1.17%	6.47%	1.97	0.10	1	2	2
14	0.00%	0.00%	0.00%	1.25%	5.73%	1.84	0.09	1	2	2

Total Runs	100	
Mean Number of MAF per Campaign of 14.0 Days	80.21	
Mean Number of Fatal Failures (Crashes) per Campaign of 14.0 Days	7.88	
Mean Number of Helicopters Lost to Enemy Action per Campaign of 14.0 Days	14.28	
Mean Repair and Turnaround Time per Entry into the Repair System	0.504024	0.004425
Mean Missions Started per campaign of 14.0 Days	152.32	
Prob of Returning to Base Safely given started a mission	0.927258	
Mean Time in High Threat Region per Helicopter per Campaign of 14.0Days	17.8017	
Mean Time in High Threat Region per Entry	1.611135	0.003693
Scheduled Time in High Threat Region	2.01686	
Mean Number of Times Individual Helicopters entered High Threat Region per Campaign of 14.0 Days	265.18	
Mean Survival Time of Individual Helicopters per Campaign of 14.0 Days	128.6829	1.893625
Mean Number of Helicopters in Repair System per hour per Campaign of 14.0 Days	1.048617	0.031614

Table 48. Data for Figure 36.

	Coverage					Helicopters				
	Percentiles							Percentiles		
Day	25%	50%	75%	se	Percent Coverage	Surviving Helos	se	25%	50%	75%
1	81.59%	85.51%	88.44%	0.50%	85.04%	22.18	0.14	22	22	23
2	85.36%	88.23%	92.95%	0.52%	88.93%	19.97	0.20	19	20	21
3	84.67%	88.52%	92.31%	0.55%	88.64%	17.51	0.24	16	17	19
4	84.15%	89.14%	92.42%	0.65%	88.51%	15.34	0.27	14	15.5	17
5	84.84%	89.08%	92.71%	0.62%	88.31%	13.06	0.31	11	13	15.25
6	84.10%	87.62%	91.61%	0.80%	87.05%	10.84	0.33	9	11	13
7	76.26%	84.73%	90.96%	1.65%	80.79%	8.74	0.34	6	9	11
8	60.07%	81.69%	89.19%	2.46%	72.40%	7.04	0.31	5	7	9
9	41.25%	59.10%	83.20%	3.03%	58.29%	5.48	0.28	3	5	7
10	23.30%	43.23%	71.01%	2.93%	43.97%	4.28	0.23	3	4	6
11	9.27%	30.37%	48.28%	2.66%	33.16%	3.54	0.20	2	3	5
12	0.00%	20.60%	43.35%	2.78%	25.94%	3.01	0.17	2	3	4
13	0.00%	0.00%	29.89%	2.20%	15.40%	2.66	0.16	1.75	2	3
14	0.00%	0.00%	13.73%	1.83%	9.42%	2.46	0.14	1	2	3

Total Runs	100	
Mean Number of MAF per Campaign of 14.0 Days	47.76	
Mean Number of Fatal Failures (Crashes) per Campaign of 14.0 Days	4.77	
Mean Number of Helicopters Lost to Enemy Action per Campaign of 14.0 Days	16.77	
Mean Repair and Turnaround Time per Entry into the Repair System	0.394097	0.003
Mean Missions Started per campaign of 14.0 Days	160.09	
Prob of Returning to Base Safely given started a mission	0.932725	
Mean Time in High Threat Region per Helicopter per Campaign of 14.0Days	21.58729	
Mean Time in High Threat Region per Entry	1.749848	0.003
Scheduled Time in High Threat Region	2.01686	
Mean Number of Times Individual Helicopters entered High Threat Region per Campaign of 14.0 Days	296.08	
Mean Survival Time of Individual Helicopters per Campaign of 14.0 Days	146.9172	1.983
Mean Number of Helicopters in Repair System per hour per Campaign of 14.0 Days	0.717077	0.019

Table 49. Data for Figure 37.

	Coverage					Helicopters				
	Percentiles							Percentiles		
Day	25%	50%	75%	se	Percent Coverage	Surviving Helos	se	25%	50%	75%
1	72.14%	77.08%	80.19%	0.54%	76.49%	21.27	0.15	20	21	23
2	79.74%	83.54%	86.79%	0.57%	83.30%	18.68	0.21	17	19	20
3	77.93%	82.91%	87.23%	0.82%	82.45%	16.08	0.26	14	16	18
4	77.56%	82.99%	87.03%	0.75%	82.68%	13.56	0.30	12	13.5	16
5	73.51%	80.21%	84.22%	0.90%	78.96%	10.98	0.33	9	11	14
6	68.92%	75.41%	83.15%	1.30%	74.48%	8.88	0.33	6	9	11
7	56.51%	72.23%	82.26%	1.95%	66.92%	6.85	0.32	4	7	9
8	41.20%	59.56%	73.17%	2.28%	55.57%	5.12	0.27	3	5	7
9	21.56%	41.09%	62.32%	2.56%	41.53%	3.68	0.22	2	3	5
10	6.14%	31.89%	43.84%	2.42%	29.72%	2.7	0.17	1	2	3
11	0.00%	10.42%	34.07%	2.33%	19.40%	2.18	0.13	1	2	3
12	0.00%	0.98%	27.89%	1.84%	14.39%	1.77	0.10	1	1	2
13	0.00%	0.00%	16.19%	1.41%	9.06%	1.54	0.08	1	1	2
14	0.00%	0.00%	6.93%	1.25%	6.63%	1.35	0.07	1	1	1

Total Runs	100	
Mean Number of MAF per Campaign of 14.0 Days	84.02	
Mean Number of Fatal Failures (Crashes) per Campaign of 14.0 Days	8.35	
Mean Number of Helicopters Lost to Enemy Action per Campaign of 14.0 Days	14.3	
Mean Repair and Turnaround Time per Entry into the Repair System	0.505856	0.004
Mean Missions Started per campaign of 14.0 Days	158.3	
Prob of Returning to Base Safely given started a mission	0.928459	
Mean Time in High Threat Region per Helicopter per Campaign of 14.0Days	18.29522	
Mean Time in High Threat Region per Entry	1.604257	0.004
Scheduled Time in High Threat Region	2.01686	
Mean Number of Times Individual Helicopters entered High Threat Region per Campaign of 14.0 Days	273.7	
Mean Survival Time of Individual Helicopters per Campaign of 14.0 Days	125.698	1.821
Mean Number of Helicopters in Repair System per hour per Campaign of 14.0 Days	1.118063	0.031

Table 50. Data for Figure 38.

	Coverage					Helicopters				
	Percentiles							Percentiles		
Day	25%	50%	75%	se	Percent Coverage	Surviving Helos	se	25%	50%	75%
1	72.68%	76.14%	81.66%	0.59%	76.56%	21.42	0.15	20	22	22.25
2	77.63%	82.90%	87.84%	0.67%	82.71%	18.77	0.23	17	19	20.25
3	76.67%	80.57%	85.82%	0.67%	81.61%	16.09	0.26	15	16	18
4	76.84%	82.37%	88.52%	0.73%	82.18%	13.54	0.30	12	14	15.25
5	74.32%	81.64%	85.18%	0.92%	79.68%	11.18	0.30	9.75	12	13
6	70.08%	80.77%	87.26%	1.48%	76.45%	8.84	0.33	7	9	11
7	53.03%	68.90%	80.43%	2.08%	64.81%	6.75	0.33	4	6	9
8	25.27%	51.17%	69.43%	2.72%	48.02%	5.09	0.28	3	5	7
9	13.22%	36.93%	60.51%	2.80%	38.63%	3.91	0.22	2	4	5
10	0.00%	27.00%	46.99%	2.53%	27.32%	3.2	0.18	2	3	4
11	0.00%	7.84%	32.00%	2.04%	17.65%	2.74	0.15	2	2	4
12	0.00%	0.00%	23.07%	1.66%	12.18%	2.32	0.11	1	2	3
13	0.00%	0.00%	7.68%	1.38%	7.65%	2.04	0.11	1	2	3
14	0.00%	0.00%	6.87%	1.26%	6.56%	1.77	0.09	1	1.5	2

Total Runs	100	
Mean Number of MAF per Campaign of 14.0 Days	81.72	
Mean Number of Fatal Failures (Crashes) per Campaign of 14.0 Days	8.17	
Mean Number of Helicopters Lost to Enemy Action per Campaign of 14.0 Days	14.06	
Mean Repair and Turnaround Time per Entry into the Repair System	0.504628	0.0049
Mean Missions Started per campaign of 14.0 Days	154.71	
Prob of Returning to Base Safely given started a mission	0.928156	
Mean Time in High Threat Region per Helicopter per Campaign of 14.0Days	17.80353	
Mean Time in High Threat Region per Entry	1.605006	0.004
Scheduled Time in High Threat Region	2.01686	
Mean Number of Times Individual Helicopters entered High Threat Region per Campaign of 14.0 Days	266.22	
Mean Survival Time of Individual Helicopters per Campaign of 14.0 Days	128.6419	1.897
Mean Number of Helicopters in Repair System per hour per Campaign of 14.0 Days	1.100086	0.034

Table 51. Data for Figure 39.

	Coverage					Helicopters				
	Percentiles							Percentiles		
Day	25%	50%	75%	se	Percent Coverage	Surviving Helos	se	25%	50%	75%
1	73.29%	77.63%	81.23%	0.61%	77.25%	21.31	0.15	20	22	22
2	78.27%	81.29%	85.79%	0.64%	82.14%	18.75	0.20	17	19	20
3	77.83%	81.89%	85.78%	0.61%	81.67%	16.33	0.24	15	16	18
4	76.88%	81.48%	87.75%	0.74%	82.19%	13.76	0.30	13	14	15.25
5	75.76%	81.15%	86.56%	0.98%	79.56%	11.4	0.33	9	12	13
6	68.29%	78.07%	84.68%	1.54%	74.19%	8.93	0.33	7	9	10
7	51.46%	70.13%	79.60%	2.17%	63.24%	6.68	0.29	5	6	8.25
8	32.33%	48.07%	66.92%	2.41%	46.90%	5.06	0.25	3	5	6
9	2.54%	30.13%	50.09%	2.72%	31.80%	4.04	0.19	3	4	5
10	0.00%	17.60%	34.50%	2.12%	20.81%	3.39	0.15	2	3	4
11	0.00%	11.75%	30.12%	1.96%	17.62%	2.79	0.12	2	2.5	4
12	0.00%	3.31%	22.90%	1.69%	12.39%	2.42	0.11	2	2	3
13	0.00%	0.00%	20.27%	1.49%	10.38%	2.1	0.09	1	2	3
14	0.00%	0.00%	9.99%	1.18%	7.34%	1.87	0.09	1	2	2

Total Runs	100	
Mean Number of MAF per Campaign of 14.0 Days	80.64	
Mean Number of Fatal Failures (Crashes) per Campaign of 14.0 Days	8	
Mean Number of Helicopters Lost to Enemy Action per Campaign of 14.0 Days	14.13	
Mean Repair and Turnaround Time per Entry into the Repair System	0.507015	0.004
Mean Missions Started per campaign of 14.0 Days	151.42	
Prob of Returning to Base Safely given started a mission	0.926925	
Mean Time in High Threat Region per Helicopter per Campaign of 14.0Days	17.44083	
Mean Time in High Threat Region per Entry	1.60081	0.004
Scheduled Time in High Threat Region	2.01686	
Mean Number of Times Individual Helicopters entered High Threat Region per Campaign of 14.0 Days	261.48	
Mean Survival Time of Individual Helicopters per Campaign of 14.0 Days	129.8026	1.911
Mean Number of Helicopters in Repair System per hour per Campaign of 14.0 Days	1.073486	0.032

Table 52. Data for Figure 42.

	Coverage					Helicopters				
	Percentiles							Percentiles		
Day	25%	50%	75%	se	Percent Coverage	Surviving Helos	se	25%	50%	75%
1	74.83%	78.41%	81.99%	0.53%	78.14%	21.53	0.16	21	22	23
2	77.59%	82.20%	85.99%	0.69%	82.27%	18.94	0.22	18	19	21
3	77.27%	82.04%	87.66%	0.67%	82.12%	16.51	0.23	15	16.5	18
4	78.83%	81.74%	87.49%	0.70%	82.30%	14.08	0.25	13	14	16
5	75.75%	81.01%	86.14%	0.89%	80.00%	11.57	0.29	10	12	13.25
6	70.59%	79.98%	84.96%	1.51%	75.45%	9.15	0.28	7	9	11
7	60.49%	72.05%	81.04%	1.95%	67.31%	7	0.25	5.75	7	8.25
8	35.49%	53.50%	69.07%	2.27%	51.85%	5.34	0.24	4	5	7
9	13.73%	31.74%	49.63%	2.56%	34.13%	4.2	0.22	3	4	5
10	0.00%	18.37%	34.78%	2.40%	23.68%	3.45	0.18	2	3	4
11	0.00%	10.62%	28.95%	1.89%	16.98%	2.78	0.14	2	3	4
12	0.00%	1.10%	26.69%	1.66%	12.37%	2.41	0.12	2	2	3
13	0.00%	0.00%	18.34%	1.33%	9.30%	2.14	0.12	1	2	3
14	0.00%	0.00%	19.08%	1.41%	9.93%	1.82	0.10	1	2	2

Total Runs	100	
Mean Number of MAF per Campaign of 14.0 Days	83.13	
Mean Number of Fatal Failures (Crashes) per Campaign of 14.0 Days	8.25	
Mean Number of Helicopters Lost to Enemy Action per Campaign of 14.0 Days	13.93	
Mean Repair and Turnaround Time per Entry into the Repair System	0.507812	0.004
Mean Missions Started per campaign of 14.0 Days	155.34	
Prob of Returning to Base Safely given started a mission	0.928608	
Mean Time in High Threat Region per Helicopter per Campaign of 14.0Days	17.90018	
Mean Time in High Threat Region per Entry	1.599778	0.004
Scheduled Time in High Threat Region	2.01686	
Mean Number of Times Individual Helicopters entered High Threat Region per Campaign of 14.0 Days	268.54	
Mean Survival Time of Individual Helicopters per Campaign of 14.0 Days	131.7001	1.910
Mean Number of Helicopters in Repair System per hour per Campaign of 14.0 Days	1.105218	0.030

Table 53. Data for Figure 43.

	Coverage					Helicopters				
	Percentiles							Percentiles		
Day	25%	50%	75%	se	Percent Coverage	Surviving Helos	se	25%	50%	75%
1	71.02%	75.76%	79.60%	0.60%	75.53%	21.47	0.15	21	22	23
2	77.34%	82.90%	87.23%	0.70%	82.09%	18.88	0.22	17	19	20
3	75.87%	81.21%	85.78%	0.67%	81.00%	16.35	0.29	15	17	18
4	77.48%	82.28%	86.33%	0.66%	81.79%	13.57	0.36	12	14	16
5	76.27%	81.35%	84.93%	0.83%	79.71%	10.91	0.37	8	11	14
6	71.58%	79.11%	85.82%	1.67%	75.18%	8.55	0.36	5	9	11
7	50.32%	72.09%	83.49%	2.41%	64.23%	6.25	0.30	4	6	9
8	16.22%	46.77%	77.28%	3.14%	46.08%	4.79	0.25	3	4	6
9	0.00%	18.45%	54.58%	3.03%	29.37%	3.77	0.19	2	3	4.25
10	0.00%	6.63%	31.87%	2.55%	20.08%	3.2	0.17	2	3	4
11	0.00%	5.45%	31.31%	2.25%	17.34%	2.71	0.12	2	2.5	3
12	0.00%	0.00%	22.80%	1.63%	11.18%	2.36	0.11	2	2	3
13	0.00%	0.00%	0.00%	1.21%	5.04%	2.19	0.10	1	2	3
14	0.00%	0.00%	0.00%	0.89%	3.20%	2.08	0.09	1	2	3

Total Runs	100	
Mean Number of MAF per Campaign of 14.0 Days	79.28	
Mean Number of Fatal Failures (Crashes) per Campaign of 14.0 Days	7.94	
Mean Number of Helicopters Lost to Enemy Action per Campaign of 14.0 Days	13.98	
Mean Repair and Turnaround Time per Entry into the Repair System	0.508803	0.004
Mean Missions Started per campaign of 14.0 Days	147.97	
Prob of Returning to Base Safely given started a mission	0.925931	
Mean Time in High Threat Region per Helicopter per Campaign of 14.0Days	17.04725	
Mean Time in High Threat Region per Entry	1.595438	0.004
Scheduled Time in High Threat Region	2.01686	
Mean Number of Times Individual Helicopters entered High Threat Region per Campaign of 14.0 Days	256.44	
Mean Survival Time of Individual Helicopters per Campaign of 14.0 Days	127.994	1.895
Mean Number of Helicopters in Repair System per hour per Campaign of 14.0 Days	0.477403	0.012

Table 54. Data for Figure 45.

	Coverage					Helicopters				
	Percentiles							Percentiles		
Day	25%	50%	75%	se	Percent Coverage	Surviving Helos	se	25%	50%	75%
1	73.10%	77.79%	81.78%	0.59%	77.54%	21.42	0.15	21	21	23
2	77.56%	82.53%	87.04%	0.67%	82.16%	18.74	0.21	17	19	20
3	75.76%	81.83%	85.94%	0.67%	81.04%	16	0.25	15	16	18
4	77.99%	82.21%	87.51%	0.72%	82.29%	13.23	0.32	11	13	15.25
5	76.25%	80.48%	84.79%	0.79%	80.23%	10.85	0.33	9	11	13
6	70.59%	79.89%	86.11%	1.67%	75.52%	8.32	0.34	5	8	11
7	51.06%	69.29%	81.76%	2.52%	62.23%	6.15	0.29	4	5	8
8	22.67%	45.01%	73.24%	2.92%	45.42%	4.78	0.23	3	4	6
9	0.00%	27.00%	46.05%	2.75%	28.69%	3.75	0.16	3	3	4
10	0.00%	14.44%	30.77%	2.35%	20.35%	3.05	0.15	2	3	4
11	0.00%	6.79%	31.29%	1.87%	14.79%	2.68	0.13	2	2.5	3
12	0.00%	0.00%	20.24%	1.64%	10.27%	2.42	0.12	2	2	3
13	0.00%	0.00%	0.00%	1.16%	5.42%	2.25	0.10	1.75	2	3
14	0.00%	0.00%	0.00%	0.79%	2.47%	2.2	0.10	1.75	2	3

Total Runs	100	
Mean Number of MAF per Campaign of 14.0 Days	78.55	
Mean Number of Fatal Failures (Crashes) per Campaign of 14.0 Days	7.89	
Mean Number of Helicopters Lost to Enemy Action per Campaign of 14.0 Days	13.91	
Mean Repair and Turnaround Time per Entry into the Repair System	0.507351	0.004
Mean Missions Started per campaign of 14.0 Days	147.53	
Prob of Returning to Base Safely given started a mission	0.926117	
Mean Time in High Threat Region per Helicopter per Campaign of 14.0Days	16.95767	
Mean Time in High Threat Region per Entry	1.595765	0.004
Scheduled Time in High Threat Region	2.01686	
Mean Number of Times Individual Helicopters entered High Threat Region per Campaign of 14.0 Days	255.04	
Mean Survival Time of Individual Helicopters per Campaign of 14.0 Days	126.6131	1.900
Mean Number of Helicopters in Repair System per hour per Campaign of 14.0 Days	0.414009	0.009

Table 55. Data for Figure 46.

	Coverage					Helicopters				
	Percentiles							Percentiles		
Day	25%	50%	75%	se	Percent Coverage	Surviving Helos	se	25%	50%	75%
1	73.99%	77.33%	81.39%	0.59%	76.89%	21.22	0.15	20	21	22
2	76.98%	81.93%	85.47%	0.66%	81.27%	18.56	0.24	17	19	21
3	78.38%	81.61%	86.81%	0.62%	81.97%	15.95	0.30	14	16	18
4	77.72%	82.63%	86.78%	0.63%	82.63%	13.29	0.35	11	14	16
5	76.34%	81.55%	84.51%	0.93%	79.77%	10.77	0.37	8	11	13
6	70.93%	77.27%	85.35%	1.91%	74.31%	8.45	0.37	6	8	11
7	48.99%	69.90%	79.39%	2.52%	61.81%	6.2	0.34	4	5.5	8
8	23.54%	46.43%	69.36%	2.89%	44.46%	4.67	0.27	3	4	6
9	0.00%	26.06%	51.26%	2.79%	28.87%	3.64	0.21	2	3	4
10	0.00%	6.87%	32.70%	2.52%	19.20%	3.07	0.16	2	3	4
11	0.00%	5.93%	28.12%	1.84%	14.29%	2.65	0.14	2	2.5	3
12	0.00%	0.00%	12.19%	1.38%	8.06%	2.34	0.12	1	2	3
13	0.00%	0.00%	15.08%	1.54%	9.58%	2.13	0.11	1	2	3
14	0.00%	0.00%	13.73%	1.35%	9.06%	1.73	0.09	1	1	2

Total Runs	100	
Mean Number of MAF per Campaign of 14.0 Days	78.8	
Mean Number of Fatal Failures (Crashes) per Campaign of 14.0 Days	7.89	
Mean Number of Helicopters Lost to Enemy Action per Campaign of 14.0 Days	14.38	
Mean Repair and Turnaround Time per Entry into the Repair System	0.506629	0.004
Mean Missions Started per campaign of 14.0 Days	148.8	
Prob of Returning to Base Safely given started a mission	0.925168	
Mean Time in High Threat Region per Helicopter per Campaign of 14.0Days	17.05889	
Mean Time in High Threat Region per Entry	1.594413	0.004
Scheduled Time in High Threat Region	2.01686	
Mean Number of Times Individual Helicopters entered High Threat Region per Campaign of 14.0 Days	256.78	
Mean Survival Time of Individual Helicopters per Campaign of 14.0 Days	125.4098	1.891
Mean Number of Helicopters in Repair System per hour per Campaign of 14.0 Days	0.47881	0.011

Table 56. Data for Figure 47.

	Coverage					Helicopters				
	Percentiles							Percentiles		
Day	25%	50%	75%	se	Percent Coverage	Surviving Helos	se	25%	50%	75%
1	71.59%	76.56%	80.47%	0.59%	76.20%	21.29	0.19	20	22	23
2	77.79%	81.60%	86.75%	0.70%	82.58%	18.67	0.25	17	19	21
3	75.75%	80.79%	85.78%	0.71%	80.70%	15.99	0.28	14	16	18
4	77.62%	82.78%	87.35%	0.67%	82.75%	13.48	0.30	11.75	13.5	15
5	75.88%	82.90%	88.37%	0.85%	81.80%	10.95	0.34	9	11	13
6	74.25%	81.40%	86.51%	1.52%	77.93%	8.61	0.35	7	9	11
7	53.93%	74.58%	82.20%	2.37%	65.65%	6.6	0.31	4	6	9
8	32.57%	58.72%	74.91%	2.94%	52.23%	4.88	0.25	3	5	7
9	0.00%	28.37%	50.35%	2.88%	30.39%	3.86	0.20	2	3.5	5
10	0.00%	14.05%	37.68%	2.41%	22.35%	3.14	0.16	2	3	4
11	0.00%	6.87%	30.78%	1.84%	16.10%	2.68	0.13	2	3	3
12	0.00%	0.00%	20.43%	1.61%	11.87%	2.3	0.12	1	2	3
13	0.00%	0.00%	20.60%	1.63%	10.84%	2.04	0.11	1	2	3
14	0.00%	0.00%	6.87%	1.22%	6.16%	1.76	0.09	1	1	2

Total Runs	100	
Mean Number of MAF per Campaign of 14.0 Days	81.28	
Mean Number of Fatal Failures (Crashes) per Campaign of 14.0 Days	8.13	
Mean Number of Helicopters Lost to Enemy Action per Campaign of 14.0 Days	14.11	
Mean Repair and Turnaround Time per Entry into the Repair System	0.50595	0.004
Mean Missions Started per campaign of 14.0 Days	153.26	
Prob of Returning to Base Safely given started a mission	0.927444	
Mean Time in High Threat Region per Helicopter per Campaign of 14.0Days	17.68068	
Mean Time in High Threat Region per Entry	1.60466	0.004
Scheduled Time in High Threat Region	2.01686	
Mean Number of Times Individual Helicopters entered High Threat Region per Campaign of 14.0 Days	264.44	
Mean Survival Time of Individual Helicopters per Campaign of 14.0 Days	127.0618	1.893
Mean Number of Helicopters in Repair System per hour per Campaign of 14.0 Days	0.510185	0.013

Table 57. Data for Figure 48.

APPENDIX D: SIMULATION DATA OUTPUT FOR ADDITONAL COMPARISONS

The following tables list extended output results from each of the simulations conducted for this thesis: They summarize measures of variability between hypothetical campaigns (100 campaigns/replications).

	Coverage					Helicopters				
	Percentiles							Percentiles		
Day	25%	50%	75%	se	Percent Coverage	Surviving Helos	se	25%	50%	75%
1	72.42%	78.04%	81.99%	0.63%	77.37%	21.56	0.16	21	22	23
2	75.31%	80.70%	86.65%	0.79%	80.96%	19.2	0.22	17	20	21
3	77.08%	80.97%	86.26%	0.72%	81.28%	16.59	0.27	15	17	18
4	77.41%	82.14%	85.61%	0.70%	81.38%	14.01	0.28	13	14	16
5	74.75%	80.94%	84.77%	0.85%	79.60%	11.4	0.33	9	12	14
6	69.67%	77.67%	84.12%	1.26%	74.92%	8.96	0.31	7	9	11
7	52.69%	71.45%	82.37%	2.36%	64.64%	6.79	0.30	4	6.5	9
8	33.47%	53.14%	73.72%	2.69%	49.92%	5.21	0.24	3	5	7
9	9.66%	33.02%	57.20%	2.74%	34.83%	4.27	0.20	3	4	6
10	0.00%	20.66%	39.82%	2.36%	24.72%	3.39	0.16	2	3	5
11	0.00%	7.78%	26.86%	1.69%	15.09%	2.83	0.13	2	2	4
12	0.00%	0.00%	14.33%	1.41%	8.83%	2.57	0.11	2	2	3
13	0.00%	0.00%	6.97%	1.15%	6.09%	2.35	0.11	1.75	2	3
14	0.00%	0.00%	0.00%	0.71%	2.56%	2.23	0.10	1	2	3

Total Runs	100	
Mean Number of MAF per Campaign of 14.0 Days	81.28	
Mean Number of Fatal Failures (Crashes) per Campaign of 14.0 Days	8.1	
Mean Number of Helicopters Lost to Enemy Action per Campaign of 14.0 Days	13.67	
Mean Repair and Turnaround Time per Entry into the Repair System	0.511009	0.004
Mean Missions Started per campaign of 14.0 Days	150.66	
Prob of Returning to Base Safely given started a mission	0.927751	
Mean Time in High Threat Region per Helicopter per Campaign of 14.0Days	17.3114	
Mean Time in High Threat Region per Entry	1.597238	0.004
Scheduled Time in High Threat Region	2.01686	
Mean Number of Times Individual Helicopters entered High Threat Region per Campaign of 14.0 Days	260.12	
Mean Survival Time of Individual Helicopters per Campaign of 14.0 Days	131.9227	1.925
Mean Number of Helicopters in Repair System per hour per Campaign of 14.0 Days	1.091719	0.031

Table 58. Data for Figure 49, and Figure 51.

	Coverage					Helicopters				
	Percentiles							Percentiles		
Day	25%	50%	75%	se	Percent Coverage	Surviving Helos	se	25%	50%	75%
1	73.17%	76.84%	81.77%	0.67%	77.05%	21.4	0.17	20.75	22	23
2	78.68%	82.56%	86.07%	0.69%	81.78%	18.73	0.25	17	19	21
3	78.33%	80.96%	85.63%	0.69%	81.77%	15.7	0.32	14	16	18
4	76.21%	81.39%	86.38%	0.78%	80.79%	13.14	0.37	11	13	16
5	73.64%	78.89%	86.38%	1.26%	77.50%	10.79	0.42	8	11	14
6	63.92%	77.97%	84.51%	2.10%	70.76%	8.55	0.39	5	9	12
7	47.30%	67.79%	80.75%	2.81%	60.26%	6.84	0.36	4	7	9
8	6.87%	55.46%	73.21%	3.22%	46.29%	5.33	0.31	3	5	7
9	0.00%	34.51%	57.71%	3.03%	33.24%	4.28	0.25	2	4	6
10	0.00%	10.13%	41.24%	2.69%	23.48%	3.51	0.20	2	3	4.25
11	0.00%	15.14%	34.38%	2.01%	18.54%	2.89	0.17	2	3	4
12	0.00%	0.00%	19.17%	1.77%	11.22%	2.55	0.14	1	2	3
13	0.00%	0.00%	0.00%	1.22%	5.49%	2.33	0.12	1	2	3
14	0.00%	0.00%	0.00%	0.98%	3.05%	2.23	0.11	1	2	3

Total Runs	100	
Mean Number of MAF per Campaign of 14.0 Days	78.07	
Mean Number of Fatal Failures (Crashes) per Campaign of 14.0 Days	7.82	
Mean Number of Helicopters Lost to Enemy Action per Campaign of 14.0 Days	13.95	
Mean Repair and Turnaround Time per Entry into the Repair System	0.505559	0.004
Mean Missions Started per campaign of 14.0 Days	147.2	
Prob of Returning to Base Safely given started a mission	0.926053	
Mean Time in High Threat Region per Helicopter per Campaign of 14.0Days	17.0081	
Mean Time in High Threat Region per Entry	1.607571	0.004
Scheduled Time in High Threat Region	2.01686	
Mean Number of Times Individual Helicopters entered High Threat Region per Campaign of 14.0 Days	253.92	
Mean Survival Time of Individual Helicopters per Campaign of 14.0 Days	129.0415	1.957
Mean Number of Helicopters in Repair System per hour per Campaign of 14.0 Days	1.052113	0.037

Table 59. Data for Figure 50.

	Coverage					Helicopters				
	Percentiles							Percentiles		
Day	25%	50%	75%	se	Percent Coverage	Surviving Helos	se	25%	50%	75%
1	72.62%	76.27%	80.91%	0.60%	76.41%	22.1	0.13	21	22	23
2	76.74%	81.25%	85.17%	0.65%	81.15%	20.3	0.20	19	20	22
3	78.81%	82.06%	87.48%	0.61%	82.75%	18.46	0.21	17	19	20
4	77.58%	82.56%	86.47%	0.77%	81.77%	16.79	0.23	15	17	18
5	76.75%	80.51%	85.46%	0.69%	80.97%	15.02	0.28	13	15	17
6	76.47%	81.33%	86.46%	0.81%	80.63%	13.53	0.29	12	14	16
7	75.25%	81.10%	86.82%	1.01%	80.02%	11.9	0.31	10	12	14
8	73.10%	79.10%	85.32%	1.42%	76.15%	10.37	0.32	8	10	13
9	58.88%	73.80%	81.95%	1.84%	68.99%	9.02	0.32	7	9	11
10	49.05%	68.69%	79.39%	2.16%	63.08%	7.76	0.30	5.75	7	10
11	38.90%	58.31%	77.18%	2.45%	55.47%	6.52	0.26	4	6	8
12	24.94%	43.59%	65.67%	2.55%	44.20%	5.31	0.22	4	5	6
13	17.96%	34.06%	45.89%	2.30%	32.32%	4.69	0.20	3	4	6
14	0.00%	18.86%	36.16%	2.32%	23.96%	4.22	0.19	3	4	5

Total Runs	100	
Mean Number of MAF per Campaign of 14.0 Days	110.14	
Mean Number of Fatal Failures (Crashes) per Campaign of 14.0 Days	1	
Mean Number of Helicopters Lost to Enemy Action per Campaign of 14.0 Days	18.78	
Mean Repair and Turnaround Time per Entry into the Repair System	0.531692	0.004
Mean Missions Started per campaign of 14.0 Days	204.53	
Prob of Returning to Base Safely given started a mission	0.950562	9.55E-04
Mean Time in High Threat Region per Helicopter per Campaign of 14.0Days	23.56841	
Mean Time in High Threat Region per Entry	1.603748	0.003
Scheduled Time in High Threat Region	2.01686	
Mean Number of Times Individual Helicopters entered High Threat Region per Campaign of 14.0 Days	352.7	
Mean Survival Time of Individual Helicopters per Campaign of 14.0 Days	175.7121	2.243
Mean Number of Helicopters in Repair System per hour per Campaign of 14.0 Days	1.706844	0.047

Table 60. Data for Figure 52.

	Coverage					Helicopters				
	Percentiles							Percentiles		
Day	25%	50%	75%	se	Percent Coverage	Surviving Helos	se	25%	50%	75%
1	75.31%	78.74%	82.50%	0.55%	78.72%	22.64	0.11	22	23	23
2	79.88%	83.64%	89.02%	0.64%	84.25%	21.42	0.15	20	21.5	23
3	79.72%	84.47%	87.62%	0.67%	83.52%	19.93	0.20	19	20	21
4	79.22%	83.58%	87.53%	0.66%	83.65%	18.6	0.22	17	19	20
5	80.09%	84.93%	88.70%	0.63%	84.20%	17.22	0.26	16	17	19
6	80.61%	84.95%	89.36%	0.65%	84.48%	15.91	0.27	14	16	18
7	77.43%	83.75%	87.70%	0.71%	82.69%	14.28	0.29	12	15	16
8	76.03%	84.19%	88.75%	0.93%	81.83%	12.95	0.30	11	13	15
9	75.73%	81.72%	86.81%	1.20%	79.25%	11.41	0.30	10	11	13
10	67.23%	79.61%	86.23%	1.43%	76.22%	10.21	0.32	8	10	13
11	65.08%	78.36%	87.22%	1.89%	73.18%	9.06	0.31	7	9	11
12	52.96%	71.22%	83.70%	2.35%	65.18%	7.93	0.32	5	8	10
13	36.51%	63.37%	79.22%	2.76%	55.79%	7.05	0.28	5	7	9
14	28.05%	53.70%	71.22%	2.95%	48.04%	6.31	0.27	4	6	8
15	12.27%	39.98%	67.14%	2.92%	39.98%	5.83	0.25	4	5	7
16	0.00%	33.79%	51.29%	2.73%	32.38%	5.27	0.22	4	5	6
17	0.00%	28.64%	41.33%	2.44%	26.34%	4.78	0.19	3.75	5	6
18	0.00%	23.40%	41.20%	2.25%	24.11%	4.31	0.18	3	4	5
19	0.00%	13.96%	36.14%	2.04%	19.71%	4.05	0.17	3	4	5
20	0.00%	11.18%	34.04%	1.81%	16.65%	3.83	0.17	3	4	5
21	0.00%	0.00%	27.47%	1.66%	12.23%	3.66	0.17	3	3	5

Total Runs	100	
Mean Number of MAF per Campaign of 21.0 Days	143.01	
Mean Number of Fatal Failures (Crashes) per Campaign of 21.0 Days	14.14	
Mean Number of Helicopters Lost to Enemy Action per Campaign of 21.0 Days	6.2	
Mean Repair and Turnaround Time per Entry into the Repair System	0.509688	0.003
Mean Missions Started per campaign of 21.0 Days	259.82	
Prob of Returning to Base Safely given started a mission	0.960858	
Mean Time in High Threat Region per Helicopter per Campaign of 21.0Days	31.16501	
Mean Time in High Threat Region per Entry	1.651637	0.003
Scheduled Time in High Threat Region	2.01686	
Mean Number of Times Individual Helicopters entered High Threat Region per Campaign of 21.0 Days	452.86	
Mean Survival Time of Individual Helicopters per Campaign of 21.0 Days	236.6388	3.227
Mean Number of Helicopters in Repair System per hour per Campaign of 21.0 Days	1.328528	0.032

Table 61. Data for Figure 53.

	Coverage					Helicopters				
	Percentiles							Percentiles		
Day	25%	50%	75%	se	Percent Coverage	Surviving Helos	se	25%	50%	75%
1	67.49%	72.24%	76.31%	0.67%	71.77%	21.48	0.15	20.75	22	22.25
2	72.25%	78.33%	81.82%	0.73%	77.27%	18.75	0.21	18	19	20
3	69.94%	77.87%	81.88%	0.82%	76.37%	16.14	0.26	14	17	18
4	63.77%	72.35%	77.96%	1.08%	70.71%	13.66	0.30	11	13.5	16
5	51.67%	60.91%	70.67%	1.41%	60.44%	11.5	0.32	9	11	14
6	44.95%	51.68%	61.45%	1.45%	51.49%	9.73	0.31	7	10	12
7	38.72%	45.57%	58.11%	1.62%	46.83%	8.26	0.29	6	8	10
8	22.74%	34.34%	47.61%	1.69%	35.45%	7.02	0.28	5	7	9
9	17.23%	30.12%	43.44%	1.90%	30.65%	6.14	0.25	4	6	8
10	9.65%	23.60%	34.86%	1.73%	25.05%	5.11	0.23	3	5	6
11	0.01%	18.18%	25.86%	1.66%	18.96%	4.41	0.19	3	4	5
12	0.00%	8.93%	23.12%	1.63%	14.28%	3.94	0.16	3	4	5
13	0.00%	0.00%	17.91%	1.39%	8.55%	3.66	0.15	3	3	4
14	0.00%	0.00%	1.78%	1.00%	4.84%	3.45	0.14	3	3	4
15	0.00%	0.00%	0.00%	0.70%	2.83%	3.37	0.14	2.75	3	4
16	0.00%	0.00%	9.48%	0.79%	5.06%	3.27	0.14	2	3	4
17	0.00%	2.03%	12.92%	0.92%	7.16%	3.01	0.12	2	3	4
18	0.00%	0.00%	12.92%	0.90%	6.49%	2.84	0.13	2	3	3
19	0.00%	0.00%	11.54%	0.83%	5.27%	2.69	0.13	2	3	3
20	0.00%	0.00%	0.00%	0.75%	3.45%	2.58	0.12	2	2	3
21	0.00%	0.00%	0.00%	0.55%	1.89%	2.53	0.12	2	2	3

Total Runs	100	
Mean Number of MAF per Campaign of 21.0 Days	119.93	
Mean Number of Fatal Failures (Crashes) per Campaign of 21.0 Days	11.97	
Mean Number of Helicopters Lost to Enemy Action per Campaign of 21.0 Days	9.5	
Mean Repair and Turnaround Time per Entry into the Repair System	0.516965	0.004
Mean Missions Started per campaign of 21.0 Days	213.48	
Prob of Returning to Base Safely given started a mission	0.947545	0.001
Mean Time in High Threat Region per Helicopter per Campaign of 21.0Days	19.79818	
Mean Time in High Threat Region per Entry	1.362338	0.002
Scheduled Time in High Threat Region	1.569978	
Mean Number of Times Individual Helicopters entered High Threat Region per Campaign of 21.0 Days	348.78	
Mean Survival Time of Individual Helicopters per Campaign of 21.0 Days	164.2024	3.049
Mean Number of Helicopters in Repair System per hour per Campaign of 21.0 Days	1.705343	0.069

Table 62. Data for Figure 54.

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9. Dr. Arthur Fries 1
Institute for Defense Analysis
1801 Beauregard Street
Alexandria, VA 22311-1772

10. LT Kevin J. Schmidt 2
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Elk Point, SD 57025